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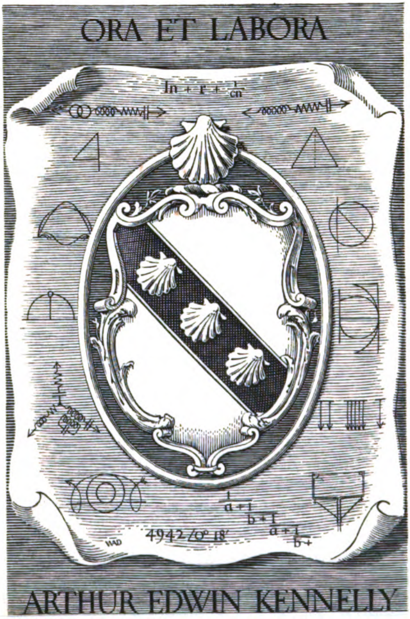

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THE ELECTRO MAGNET

BY

TOWNSEND WOLCOTT,
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RICHARD VARLEY.

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THE ELECTRO MAGNET.

General Properties.

1. The electro magnet is like the ordinary or permanent magnet in all of its properties, except that its magnetism is only maintained by the inductive influence of an electric current, and disappears as soon as this inducing or magnetizing current is stopped or withdrawn. It is necessary, therefore, in the study of the electromagnet, to consider some of the properties of the permanent magnet, or more properly we must begin with the properties of magnetism in the abstract.

The first thing to be noticed about a magnet is that it attracts iron. The next thing is that all parts of it do not attract the iron with equal force, but that certain definite portions of the surface possess more attractive power than the rest. These spots are called poles, and are usually situated at or near the ends, if the magnet have an elongated form, as is the case with most artificial magnets, whether electro or permanent magnets. Natural magnets are usually rough, irregular lumps of iron ore, and the location of the poles is not so definite.

The next property observed is that all magnets have two poles, and that the poles are of opposite nature. If we suspend any magnet so that it may turn freely, it will come to rest in such a position that a straight line drawn through the two poles will point north and south, or at least approximately so. The pole of the magnet that points toward the north pole of the earth is called the north pole of the magnet, which is the most natural way, although, as will presently be seen, this nomenclature necessitates calling the magnetic pole of the earth, which is situated at or near the geographical north pole, the magnetic south pole of the earth. If we take two magnets and bring their north poles together (that is, the pole of each which we have found by experiment points toward the geographical north pole), we find that they repel one another; we find likewise that the two south poles repel one another, while the south pole of one magnet attracts the north pole of the other, and vice versa. We see then that like poles repel and unlike poles attract, from which it is evident that the north pointing or north

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seeking pole of the magnet must be of opposite kind to the north pole of the earth, so that as we call this north pointing pole the

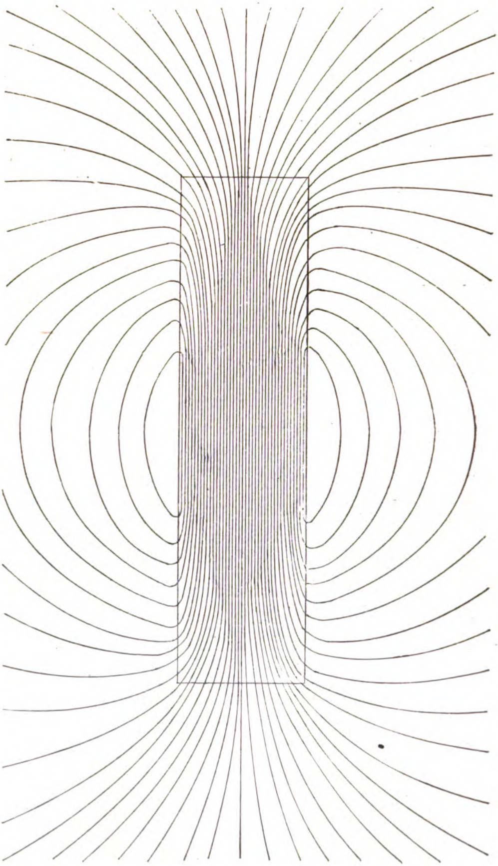

FIG. 1.

north pole of the magnet, we must call the magnetic pole at the north pole of the earth a magnetic south pole.

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2. Every magnet then has a north and a south pole, but more than this, these two poles are always equal in strength. This at first sight does not seem to be true, because a piece of iron will frequently stick to one pole much tighter than to the other, but this is due to the fact that the magnetism on the apparently strong pole is crowded into a smaller space than on the other pole; when the strength of the poles is properly measured, they are always found to be of exactly the same strength. In a bar magnet, Fig. 1, the external magnetism is nearly all concentrated at or near the ends, the middle portion being entirely free from it. If, however, the magnet be broken in the middle, it will be found that the broken surfaces are now poles, each of the opposite kind to the old pole at the other end of the piece, so that each piece is now a complete magnet.

Any magnet may be broken into any number of pieces, and each piece will still be a complete magnet with two poles. Moreover, the strength of the two poles of any one of these magnetic fragments is equal, for if it were possible to break a magnet in such a manner that one of the poles of one of the fragments was stronger than the other in any degree, it would be possible to break this fragment in such a manner that there would be two fragments, one with equal poles and one with only one pole. Now in the smallest fragment in which magnetism can be detected at all, two poles can be detected, although they may be too small to be measured.

Magnetic Field of Force.

3. The space about the poles of a magnet, where the magnetic force is found, is called the magnetic field, or field of force. If in this field of force a line be drawn, so that at each point in its length it coincides in direction with the magnetic force at that point, this line is what is called a magnetic line of force. These lines may be shown experimentally by laying a smooth sheet of paper over a magnet, sprinkling fine iron filings on the paper and gently shaking it so that the filings may more easily find their places. Fig. 2 shows some experimental lines of this kind. This experiment shows the existence of the lines of force, or lines of induction, as they are sometimes called, in the vacant space around

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the magnet, but theory calls for them inside the substance of the magnet, and we know by indirect experiment that the magnet is magnetized internally, so in our reasoning we always suppose the lines of induction to go through the substance of the magnet, out through the north pole, around through the air to the south pole and back to the starting point. This is the positive direction of a line of magnetic induction, according to the accepted convention.

Lines of magnetic induction are, invariably and in all circumstances, closed curves. This principle was not generally recognized

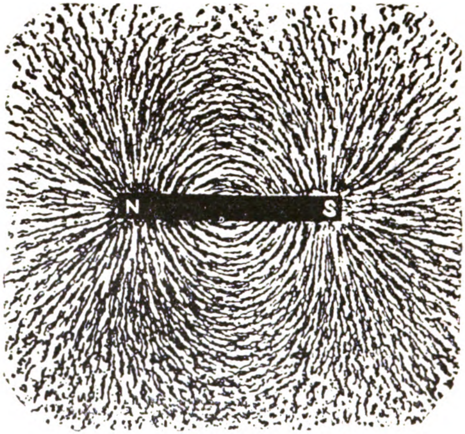

FIG. 2.

for a long time, yet it is a mathematical deduction from the principle that every magnet has two equal opposite and inseparable poles, which principle we have just considered, and of the existence of which no one has any doubt. It may seem at first that it is unnecessary to have two names for these lines, but there are two distinct properties belonging to them. First, as we have seen, they indicate by their direction at every point, the direction of the force, and also, by their closeness to each other, the intensity of the force, for which reason they are called lines of force; but they

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are also connected with another important phenomenon, namely, the induction of electric currents, and as the total number of these lines, other things being equal, determines the electromotive force that can be induced by a magnet, they are called lines of induction also. Although in the space around the magnet, or field of force, the magnetic force and magnetic induction are numerically equal, this is not the case within the substance of the magnet, and it is impossible to clearly understand magnetic phenomena without distinguishing between force and induction. The intensities of magnetic force and of magnetic induction are represented algebraically by the French script letters $\mathcal{H}$, and $\mathcal{B}$, respectively.

4. Although the poles of a magnet cannot be separated in fact, we separate them in our minds for the purpose of facilitating the reasoning process, just as we concentrate our attention on one end of a rope as though the other end did not exist, although the rope, so long as it remains a rope properly speaking, must have two ends. If we assume a north pole concentrated at a point, and attracting according to the general law for central forces, inversely as the square of the distance, the lines of force will be straight, and will radiate equally in all directions, the positive direction being outward. If we assume a similar south pole of the equal magnitude, everything else will be the same except that the positive direction of the lines of force will be inward.

Now if these poles be placed near together, the force at any point in their neighborhood consists of two components, one from each pole, and if these components be compounded according to the usual parallelogram law, it will be found that the resultant lines of force are not straight, but are curves issuing from the north pole, and vanishing in the south pole. This will answer the question frequently asked, why is it that if magnetic attraction follows the same law as the attraction of gravitation, that magnetic lines of force are always curved, while gravity acts in straight lines. It is because magnetism is bipolar, and in the simplest possible case, we are dealing with the resultant force from two poles. Even in the case of gravity, the field of force produced by two or more separate bodies contains curved lines of force.

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Magnetic Units.

5. We may now intelligibly define the magnetic units. The starting point for these is the unit magnetic pole, which is defined as a pole of such magnitude that it repels an exactly similar pole at unit distance, with one unit of force. The electric and magnetic units now in general use are based upon the metric system. Starting with the centimetre as the unit of length, the gramme as the unit of mass and the second as the unit of time, we can, by means of the known relations of physical phenomena to each other, so define the units of all the other physical quantities that their magnitudes will be determined by those of the centimetre, gramme and second. This system is called the centimetre-gramme-second system, which name is usually abbreviated C. G. S. In this system the unit of force is called the dyne, and is defined as the force necessary to produce unit acceleration in one gramme; unit acceleration being an increase of the velocity of one centimetre per second for each second the force acts. That is, if a gramme be perfectly free to move, as when it is let fall, for example, if it be subjected to the force of one dyne, it will at the end of one second be moving with the velocity of one centimetre per second, or at the end of any time, it will be moving at the rate of as many centimetres per second as the number of seconds the force has been acting. A falling body at Greenwich, England, at the end of the first second has acquired a velocity of 981 centimetres per second; that is to say, the force of gravity on one gramme is 981 dynes, from which it follows that the *force* of one dyne is not very different from the *weight* of one milligramme; that is the pull of gravity on the *mass* of one milligramme. The force of gravity varies somewhat in different parts of the globe, but the variation is not very large. The C. G. S. units for the electric quantities are for the most part of an inconvenient size, so they have been replaced by multiples, the multiplier in every case being a power of ten, so that the simplicity of the relation is not interfered with. Thus 10^8, or one hundred million C. G. S. units of electromotive force (abbreviated E. M. F.), are taken as the practical unit of E. M. F. and called the volt: 10^9 or one thousand million units of resistance are taken as the practical unit of resistance and called the ohm: $\frac{1}{10}$ of the C. G. S. unit of

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current is taken as the practical unit of current and called the ampere. For the magnetic quantities the C. G. S. units are adopted without change. In the C. G. S. system, and also in the practical system, the unit pole is one that repels an exactly similar pole at one centimetre distance, with the force of one dyne. To make the matter clear, imagine two exactly similar poles, either both north or both south, concentrated upon two respective points one centimetre apart; then if the mutual repulsion between these poles is one dyne, they are both unit poles. If one is a north and one a south pole, everything will be the same except that there will be an attraction of one dyne instead of a repulsion.

If the lines of force radiate uniformly in all directions from one of these unit poles and act with the force of one dyne on the other pole as assumed, at one centimetre distance, then we say that the force has unit intensity at one centimetre distance. Now conceive a spherical surface of one centimetre radius, with the pole at its centre, then the force and consequently the induction, as we shall see later, is of unit intensity all over the sphere. We know by geometry that the superficial area of a sphere of one centimetre radius, is 4π square centimetres, (the Greek letter π, called pi, denoting the ratio of the circumference of a circle to its diameter, that is 3.1415927), therefore if we define the unit quantity of magnetic induction, as the quantity of induction through one square centimetre of surface where the *intensity* is unity, we must of course have 4π units of quantity of induction through the whole surface of the sphere. The unit intensity of magnetic induction is called the gauss, and the unit quantity is called the weber. At one centimetre from the unit pole, therefore, the intensity of the induction is one gauss, and the total induction coming from unit pole is 4π webers, that is 12.56637 webers.

Induced Magnet, Reluctance, Permeability.

6. We next observe that when a magnet attracts a piece of iron, the iron itself becomes a magnet for the time being. That is, if a piece of iron be held within a short distance of the pole of a magnet, as in Fig. 3, it will itself attract other pieces of iron, as shown. The iron is said to become a magnet by induction. It

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seems as though a magnet did not attract iron directly, but first magnetized it and then attracted the magnetism in it. There are then three magnetic quantities which are really distinct, and which should be carefully differentiated in theory, but which are frequently confused. They are, first, the quantity of magnetism, the

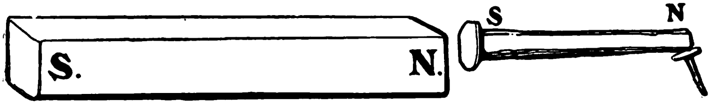

FIG. 3.

unit pole being the unit quantity; second, the magnetic force, the intensity of which at any point is measured by the mechanical force exerted on a unit pole placed at that point, and the total quantity of which issuing from a unit of magnetism or unit pole, is 4 π units, while the total quantity, or flux as it is called, through any surface, is equal to the area of the surface multiplied by the intensity of the force; and third, the magnetic induction, which in the air space has the same numerical value as the force, but in the substance of the magnet a different value, which will be investigated further on.

Just as in the study of electric currents, we have electric potential producing a flow of current, so in magnetism we have magnetic potential, which produces a flux of magnetic induction. Just as every known substance offers some resistance to the passage of electric current, so every known substance offers some obstruction to the passage of magnetic induction. This magnetic resistance is called, for the sake of greater distinction, magnetic reluctance or simply reluctance. In the place of specific magnetic conductivity, we have permeability. Permeability is denoted by the Greek letter μ, called mu. The permeability of air is taken as unity; that is the foregoing definition of unit pole assumes unit permeability. The permeabilities of other gases, vacuum, and in fact of all bodies except a few, are very nearly unity also. It is a fact that the permeabilities of most bodies are slightly greater or slightly less than unity, but the differences are so small that they can only be detected by very accurate experiments, and are of no practical importance whatever in the designing of magnets. The

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permeabilities of cobalt and nickel are much greater, being as high in some cases as 200 or 300, but for engineering purposes some kind of iron or steel is always used, iron being by far the most magnetic metal, the permeability of the best iron reaching 2500 or more under favorable conditions.

7. The permeability of air is a constant, whatever the intensity of the force, so that in the air the force and induction are always numerically the same. In iron, however, the permeability, although always greater than unity, is not a constant even in the same specimen, so the induction, although always greater than the force, is a variable number of times greater, according to the magnitude of the force. There is a limit to the magnetizability of iron, so as the magnetizing force increases, the permeability decreases, and the induction, although it still increases somewhat, does so more and more slowly, until at last there is very little change in the iron, and it is said to be saturated.

If the force be of constant intensity along a line of induction, then there is one unit difference of potential per centimetre, for each unit intensity of the force. The unit of magnetic potential is called the gilbert. If, therefore, we have in a magnetic field a difference of potential of one gilbert per centimetre, the intensity of the induction is one gauss, or in other words the flux of induction is one weber per square centimetre. Such a field is called a uniform field of unit intensity. The magnetic field of the earth is sensibly uniform over moderate distances, and has a total intensity, or intensity of total force of about .61 gauss in the neighborhood of New York, the dip or inclination to the horizon being about 72° so the horizontal component of the force, which is the quantity usually given in records of magnetic observations, is about .19 gauss.

Discovery of Electromagnetism.

8. Permanent magnets have been known for many centuries, but not until the year 1820 was it known that the electric current has magnetic properties. In that year Örsted published an account of a discovery of his, which, briefly stated, amounts to this: If a compass needle be brought near a wire carrying an electric current,

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it tends to take up a position at right angles to the direction of the wire, there being a definite relation between the direction of the north end of the needle and that of the flow of current, best defined as follows. If we look along the wire in the direction of the current, that is if we stand at the positive end and look toward the

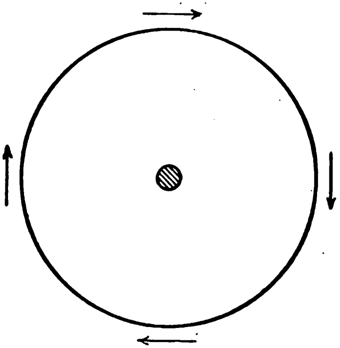

FIG. 4

negative end, the compass needle points "clockwise": that is, if the needle be above the wire, the north pole points to the right; if to the right of the wire, the north pole points downward; if below the wire, the north pole points to the left, and if to the left of the

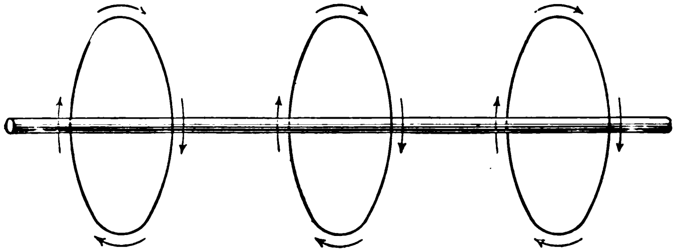

FIG. 5

wire, the north pole points upward. In other words, if we move the compass needle in the direction in which its north pole points, it will revolve about the wire in the direction of the hands of a

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clock, as viewed from the positive end of the wire. This is illustrated in the diagram Fig. 4, and the same relation between the directions of compass needle and current, but viewed from a different point, is shown in Fig. 5. If this experiment be tried under ordinary conditions, there is always a disturbing influence from the earth's magnetism, and the compass needle can never be made to set itself at right angles to the wire in all positions; but if the earth's field be perfectly neutralized so that the compass needle will point indifferently in any direction so long as there is no current in the wire, when there is a current it will point not only in a direction at right angles to the wire, but also place itself with its two poles equidistant from the wire: that is, it will take up a position tangent to a circle, through the center of which the wire passes.

This being true it is obvious, first that there is a magnetic field of force about the wire, and second that the lines of force are concentric circles with the wire at their center. It may be shown experimentally, and may also be proved by the higher mathematics, that the intensity of the force along any one of these lines, or along any two of the same diameter, is the same at every point, while along different lines the force is less the greater the diameter of the circle. In other words the force is inversely proportional to the distance from the center of the wire, but at a given distance from the center it is the same on all sides of the wire and at all points along its length. The units of the C. G. S. system are so defined that at one centimetre from the center of the wire the intensity of the force is 2 with unit current, and at any other distance a, and current I it is $\frac{2\,I}{a}$, but as in practical work we always use the ampere as the unit of current, the force in gausses is $\mathcal{H} = \frac{.2\,I.}{a}$

Iron Ring in the Magnetic Field.

9. In the field about the wire $\mathcal{B} = \mathcal{H}$ of course so long as there is no magnetic material there, but we will now suppose a ring of annealed wrought iron of rectangular cross section to be placed concentrically about the wire and then note the relation between $\mathcal{H}$ and $\mathcal{B}$. Suppose the wire is carrying 50 amperes, then at 1 cen-

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timetre distance $\mathcal{H}=10$. At which value of $\mathcal{H}$ a fair value of μ for good wrought iron is 1200, which means that $\mathcal{B}=1200\,\mathcal{H}=12000$ gausses. At 2 centimetres $\mathcal{H}=5$ at which value $\mu=2000$ say, and $\mathcal{B}=2000\mathcal{H}=10000$ gausses. At 10 centimetres $\mathcal{H}=1$, but here μ is smaller again, say 1000, and $\mathcal{B}=1000\mathcal{H}=1000$ gausses. We see from this simple calculation that although we can always be certain that the value of $\mathcal{B}$ in the iron is greater than that of $\mathcal{H}$, and consequently than that which $\mathcal{B}$ would have in the air, were the iron not there, yet we cannot tell how much greater until we know all about the particular piece of iron that we are dealing with. In this example we have derived the induction $\mathcal{B}$ from the force $\mathcal{H}$, because we knew the latter at every point, but we also know the difference of magnetic potential, or magnetomotive force, between any two points on a line of force. In Figs. 6 and 8 there are sets of lines cutting the lines of force or induction everywhere at right angles, or orthogonally as it is called; these are what are called equipotential surfaces, (or strictly the intersections of the equipotential surfaces with the plane of the paper). All points on any one of these curves are at the same magnetic potential, and a unit magnetic pole placed on one of them and free to move along the curve, but not in other directions, would not be moved at all by the magnetic force. The magnetomotive force between two of these curves is of course the same for any point on one curve and any point on the other curve. Magnetomotive force is abbreviated M. M. F. and is represented algebraically by the French script letter $\mathcal{F}$.

Since the force at any point is $\mathcal{H}=\frac{.2\,I}{a}$, the magnetomotive force must be $\frac{.2\,I}{a}$ gilberts per centimetre, and as the circumference of any one of the circles is $2\,\pi\,a$ centimetres, the total magnetomotive force around the circumference is $\mathcal{F}=\frac{.2\,I\,2\,\pi\,a}{a}=.4\,\pi\,I$ gilberts. We see then that the total gilberts clear around are the same for all the circles, regardless of the radii, which is an important thing to remember. The foregoing case was considered first because it is the simplest possible case of an electromagnet, but it is not a practicable

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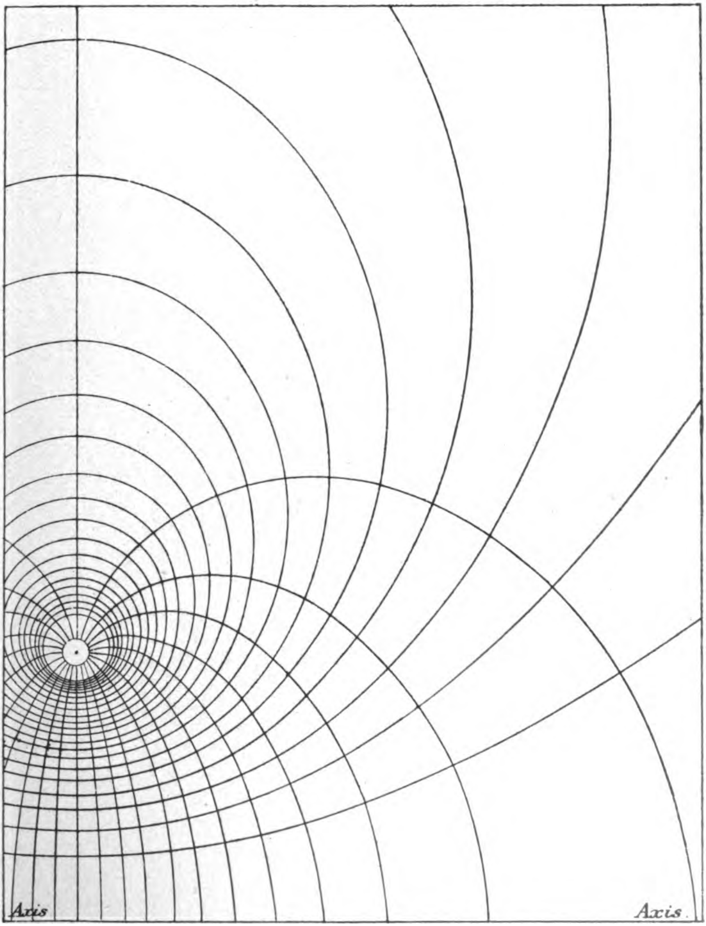

Circular Current.

FIG. 6.

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form, and it should be borne in mind that as an electric current must flow in a closed path, a wire bent into a circular form is much more practical. Suppose then that we have such a circular conductor, and investigate the field of force. We find it as shown in Fig. 6. The intensity of the force at any point cannot be expressed as before by simple algebra, but it can be expressed by means of the higher mathematics. In the center however, the force is

$$\mathcal{H} = \frac{.2\pi I}{A} = \frac{.62832\ I,}{A}$$

which is the same as the expression for the force about a straight wire except that A, the radius of the circuit is substituted for a, the distance from the wire. At any distance, x, from the center, on the axis X, the force is

$$\mathcal{H} = .2\ \pi \frac{I A^2}{(A^2 + x^2)^{\frac{3}{2}}} = .2\ \pi \frac{I\ A^2}{S^3}$$

(where

$$S = \sqrt{A^2 + x^2},$$

that is the slant distance from the given point to the axis of the conductor, as shown in Fig. 7), but at points off the axis

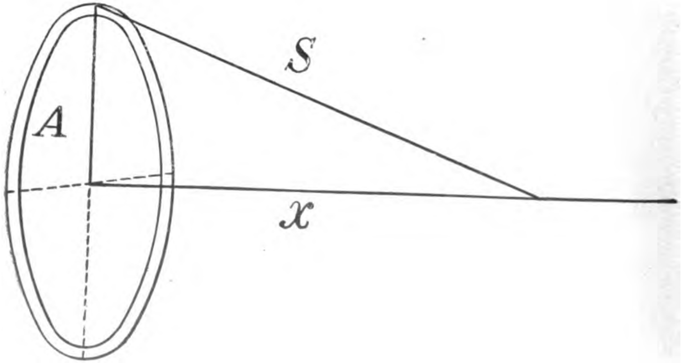

FIG. 7.

the force cannot be expressed by a simple algebraic equation, but in all cases it is approximately uniform near the center, increasing somewhat toward the wire, while very near the wire it is much

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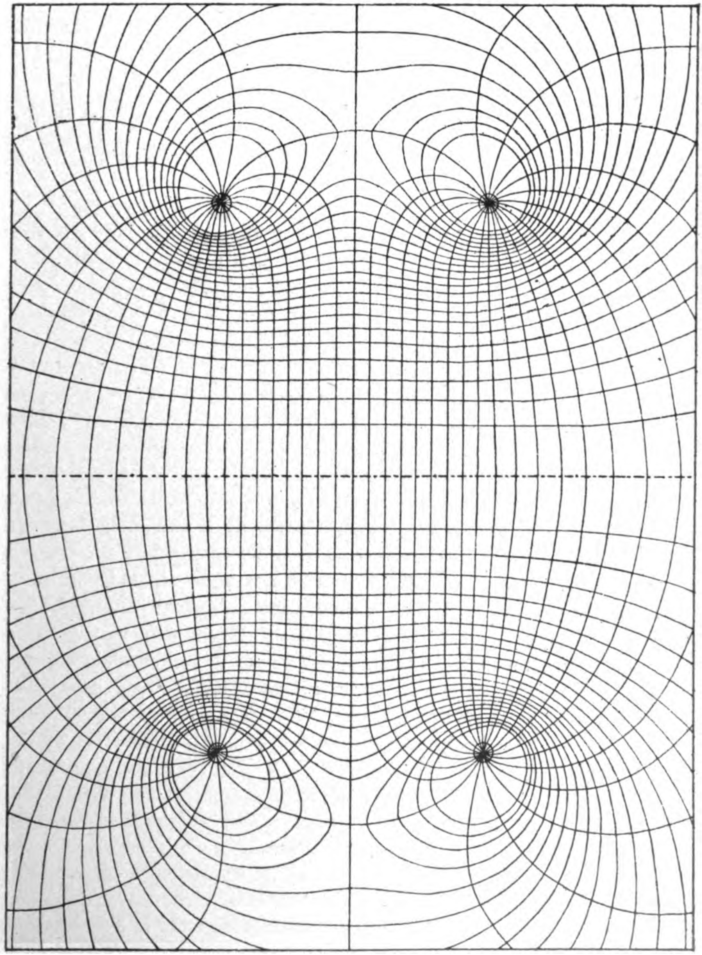

FIG. 8.

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greater, especially if the diameter of the wire is small as compared with the diameter of the circuit. It will be seen in Fig. 6 that the lines of force are no longer simple circles, but are distorted into more or less oval shapes, the more so the further from the wire; those very near the wire being only slightly distorted. The M. M. F. measured clear around the magnetic circuit, still, however, is $\mathfrak{F} = .4\,\pi\,I$ gilberts.

10. Placing another circular circuit exactly like the first one in all respects, parallel and coaxial therewith, we have a distribution of force shown in Fig. 8. Here, it will be observed, the force is very nearly uniform near the center, and is not very variable except quite near the wires, as indicated by the relative curvature of the lines of force. This arrangement of two circular currents is employed in one form of galvanometer, where it is necessary to have a uniform field of force, a needle being used, whose length is not more than one-tenth or one-twelfth of the diameter of the circles, and whose center is placed in the center of the space between the currents. Within the space occupied by such a short needle the force is pretty accurately uniform. If the space between the two circular currents be filled in with other circular conductors carrying equal currents, the field will be stronger and a little more uniform, especially near the conductors. Instead, however, of placing a number of separate conductors side by side in this manner, in practice a single wire is usually wound into a spiral or helix, the turns or convolutions of which are only sufficiently separated to allow insulation between them. The diameter of the convolutions is usually quite large, as compared with the diameter of the wire, in which case the pitch of the helix is very slight, and the field of force is sensibly the same as for the separate circles. This is more particularly the case when there are two layers of wire, for in that case the pitches of the two spirals are opposite,—that is, one is a right handed and the other is a left handed screw,—and any tendency of one layer to distort the field is counteracted by the other layer. When there are more than two layers, they are alternately right and left handed, so that the field is not perceptibly distorted, even where, as is sometimes the case, two or more wires are wound at a time side by side instead of a single wire, thus making the

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pitch of the spiral comparatively steep. The M. M. F. clear around the magnetic circuit is $.4 \pi \ I \ N$ gilberts, N being the number of convolutions in the coil. The forms of the lines of force in a coil of several layers are shown in Fig. 9. Inside the coil, especially toward the middle, the force is nearly uniform, but outside it spreads in all directions. The general form of the lines of force is like that of a

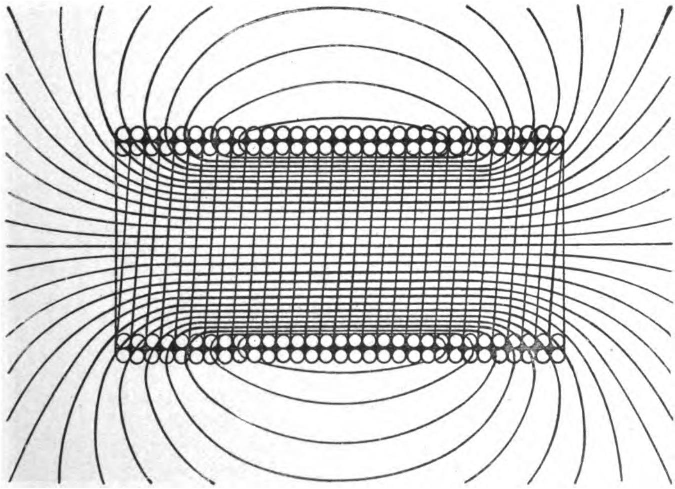

FIG. 9.

permanent bar magnet shown in Fig. 1, but if a soft iron core is introduced the resemblance is still greater, as may be seen by Fig. 10. In fact the two magnets are practically identical in the distribution of their magnetism and the form of their fields.

Calculation of Magnet Windings.

11. If the convolutions of a coil be of some other shape than circular, the distribution and shape of the lines of force is of course different, but the total M. M. F. measured clear around the magnetic circuit is always expressed by the equation M. M. F. $= .4 \pi \ I \ N$ gilberts. This is accurately true no matter what the form of the

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convolutions or how they are disposed in relation to each other, whether in a long or a short coil, or whether the coil have a straight

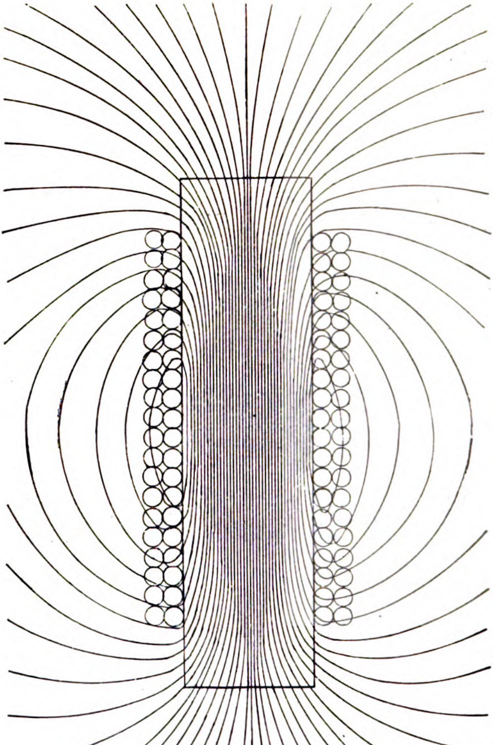

FIG. 10.

or curved axis, &c. As the M. M. F. is always proportional to the product of the number of convolutions or turns in the coil. multi-

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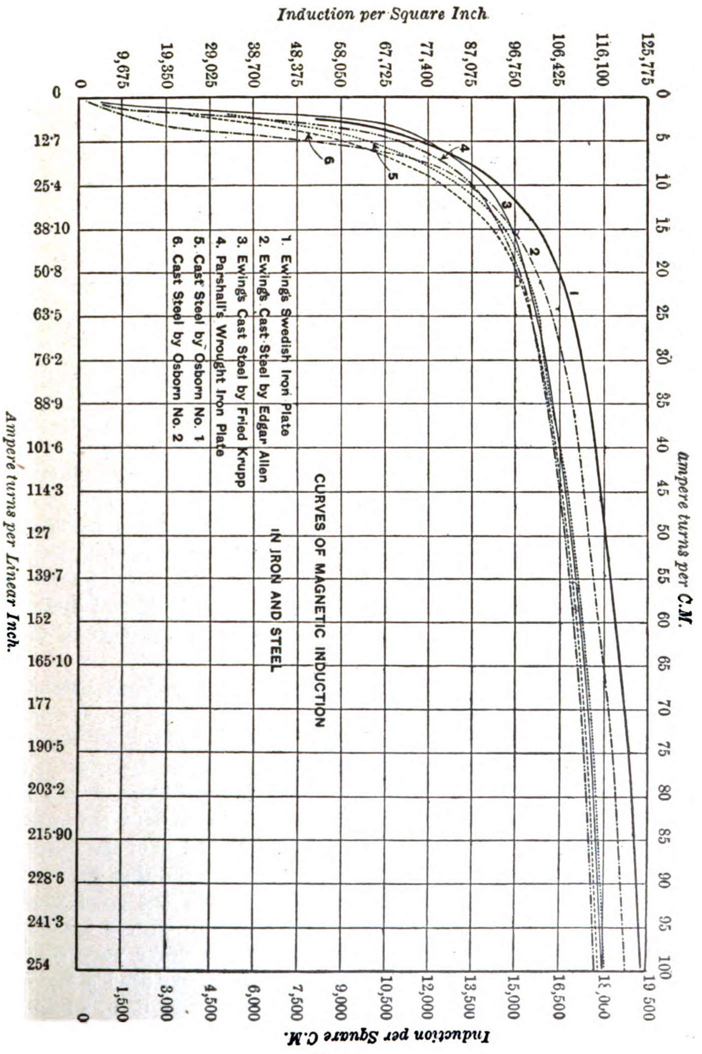

Fig. 11.

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plied by the current that is flowing, this product has been called ampere-turns, and the ampere-turn adopted as a unit of M. M. F. instead of the gilbert. The ampere-turn is of course equal to $.4\pi = 1.2566$ gilberts, and the M. M. F. of any coil is $I\ N$ ampere-turns. In practical work the ampere-turn is usually more convenient than the gilbert, owing to the fact that the two things most important about an electromagnet are the number of turns of wire on it and the number of amperes carried by the wire. If in calculating a magnet we use gilberts, we must afterwards convert into ampere-turns, so as to know how many turns of wire to put on it, and how much current to use; while if the data be so arranged that ampere-turns may be used in the calculation, there is no object in introducing gilberts at all. In calculating a magnet we must know the properties of the particular iron to be used in the construction, especially the intensity of the induction $\mathfrak{B}$, for any given magnetizing force. This may be expressed in terms of the magnetic force $\mathcal{H}$, the gilberts per centimetre (or per inch) of length, or the ampere-turns per centimetre (or per inch) of length. Some electricians also prefer to express the intensity of the induction itself in inch measure instead of metric; that is, in webers (lines) per square inch, instead of webers per square centimetre or gausses. There are, therefore, in common use several different ways of calculating electromagnets, based on the different units employed.

In Fig. 11 there are several of these methods combined in one diagram: at the top of the diagram the abscissae are numbered to represent ampere-turns per centimetre, and at the bottom of the diagram to represent ampere-turns per inch; the ordinates likewise being numbered at the right hand of the diagram to represent intensity of induction in webers per square centimetre, that is, in gausses, and at the left hand of the diagram to represent webers per square inch. Fig. 11 contains curves for six different kinds of iron and steel, all of which are good from a magnetic point of view. It will be seen that the curves are all of the same general form, and that they do not differ very greatly from one another. These curves are taken from Snell's Electric Motive Power. In Fig. 12 are some curves of cast iron, which, as will be seen, is very much inferior to the iron and steel of Fig. 11.

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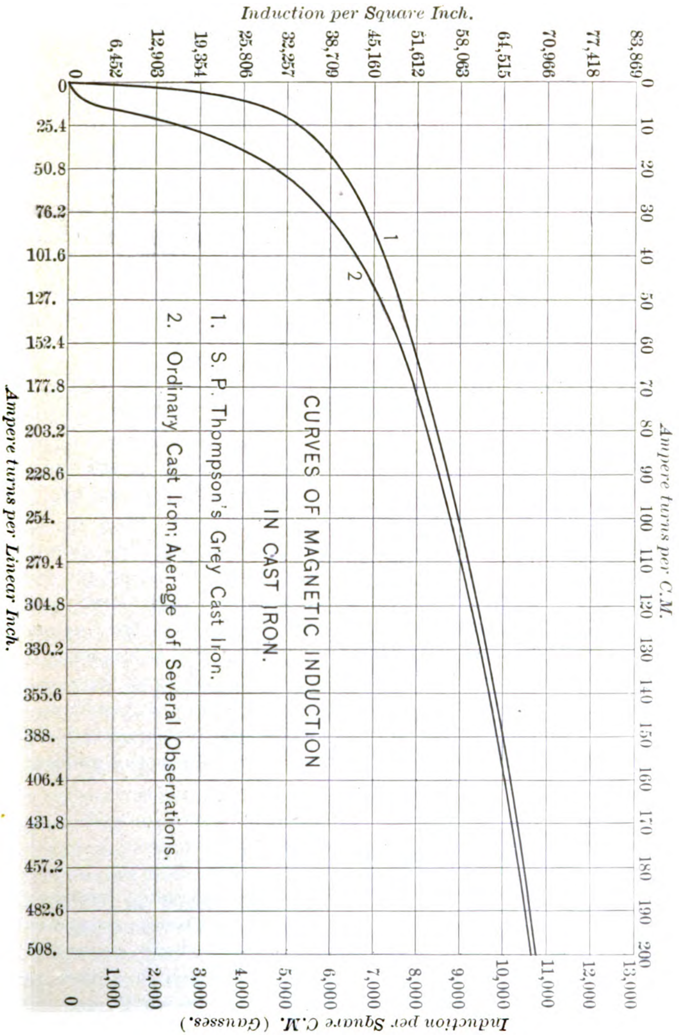

FIG. 12.

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Cast iron was formerly very largely used in the construction of the field magnets of dynamo machines on account of its cheapness ; but owing to the far better quality of some grades of steel, which may be cast almost as readily as cast iron, the use of cast iron has greatly decreased. A magnet of cast steel is often actually cheaper as to first cost than one of cast iron, owing to the saving in weight, notwithstanding a somewhat greater cost per pound. In addition to the mere question of first cost, there are other considerations, such for example as economy of space and of weight, which in some apparatus are of much greater importance, moreover the cost of the core is only a small part of the total cost of any magnet, and especially of small ones, and the better the core the less wire is required in the winding to produce a given result. All these things are favorable to the use of good iron or steel for magnet cores, and in the construction of small magnets, which are more particularly the subject of this article, nothing should ever be used or even considered for use except the very best material obtainable. Another important consideration in winding small magnets is the insulation on the wire. In the case of fine wire the insulation must be very thin not to take up an amount of space altogether out of proportion to that occupied by the bare copper wire itself, and in this case a very slight variation in the thickness of the insulation will be considerable as a percentage variation, and when many hundreds of turns are wound on, as is frequently the case, the accumulation of errors is very considerable. For example, the variation of one-thousandth of an inch in the thickness of the insulation on a No. 36 wire will make over 25 per cent. variation in the amount of wire that can be wound in a given space.

Magnetic Circuit.

12. We have seen that there is a certain analogy between the magnetic field and the electric circuit, and in modern engineering practice the term magnetic circuit is used very generally to describe the magnetic part of any apparatus which has such part. There is the magnetic potential or M. M. F., from which results the flux of induction, very much as in the case of electricity there is electric potential or E. M. F. causing a flow of current. Moreover,

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the lines of magnetic induction are always closed curves (see art. 3), just as are the lines of flow of electric current, so there must always be a closed magnetic circuit, just as there must always be a closed electric current in order to have a flow of current. When the magnetic circuit consists partly of iron and partly of air space, it is sometimes called an open magnetic circuit to distinguish it from a circuit which is wholly of iron and which is called a closed magnetic circuit. Strictly speaking, however, there is no substance which acts as a magnetic insulator, and so it is impossible to open a magnetic circuit in the sense in which an electric circuit is opened; namely, by interposing a complete insulator in the path of the current. The only effect of introducing an air gap into a magnetic circuit is to somewhat reduce the total induction through the circuit, like introducing a resistance into an electric circuit. The permeability of air, as before remarked, is unity, and although some substances have a slightly lower permeability than air, the difference is unimportant from an engineering point of view, and there is nothing that even approaches zero permeability, which would be the essential property of a magnetic insulator. We have already seen that the total M. M. F. clear around any magnetic circuit whatsoever is $.4 \pi N I$ gilberts, or $N I$ ampere-turns. This expression is perfectly correct in all cases, but the calculation of the intensity of the force and induction at any given point, is a problem of such complexity that it has never been solved for all cases with perfect accuracy, but fortunately an approximation to the true solution sufficiently close for engineering purposes may usually be obtained without much difficulty, and without the use of the higher mathematics. The magnetic circuits most used in good engineering practice are for the most part of iron, with air gaps as few and as narrow as possible, and with changes of density of flux as gradual as possible. These things all contribute toward the easy calculation of the elements of the magnetic circuit.

Suppose we have a magnet frame like that shown in Fig. 13, and we wish to calculate a winding for it to produce a given result: say to magnetize the cores up to 16,000 gausses when the armature is on, we proceed as follows: The cores are 2 inches long each, 4 inches or 10.2 centimetres taken together. We will suppose the frame made of Ewing's Swedish iron; looking in the curve diagram Fig. 11 we

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find that at 16,000 gausses there are required about 17 ampere-turns per centimetre of length, or $10.2 \times 17 = 173.4$ ampere-turns for the cores alone. The yoke and armature are $\frac{7}{16} \times \frac{1}{4}$ inch, or .1194 square inch cross section, while the cores are $\frac{3}{8}$ inch in diameter, or .1105 square inch cross section, so $16{,}000 \times .1105 \div .1194 =$ 14.800 gausses induction in the yoke and armature, allowing nothing for leakage. As only the ratio of the cross sections was needed, it was not necessary to reduce them to square centimetres, although gausses were used in the calculation. The lines of induction are very nearly straight in the cores, so the assumption of the length of the cores as the length of that part of the magnetic circuit which

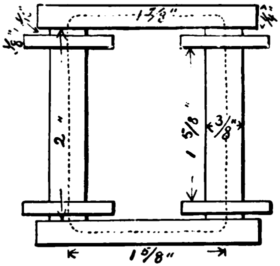

FIG. 13.

the cores form, is a legitimate one. In the yoke, however, the lines of induction bend around somewhat after the manner of the dotted line in Fig. 13 and the length of this line between the points *a* and *b* may be considered a fair average length of this part of the magnet circuit. Thus in the yoke and in the armature each, there are $1\frac{7}{8}$ inches of circuit or in both together $3\frac{3}{4}$ inches or 9.5 centimetres. Consulting the curve for Swedish iron we find at 14,800 gausses, 12 ampere-turns per centimetre, or $12 \times 9.5 = 114$ ampere-turns for the yoke and armature, which gives $173.4 + 114 = 287.4$ ampere-turns in all for the whole magnetic circuit.

13. This simple example illustrates the method of calculating the ampere-turns for a magnet, though of course some cases occurring in practice are much more complicated than this one. If

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we wish to know the total flux in the magnet just calculated, we of course find the area of cross section of the core in square centimetres and multiply it by 16,000. That is .1105 square inches equal .713 square centimetres, or the total flux is $.713 \times 16{,}000 = 11408$ webers. If the armature be raised from the poles so as to introduce an air gap in the circuit, the magnetic reluctance is greatly increased, for the permeability of air being only 1, it requires 1 gilbert M. M. F. per centimetre for each gauss of intensity of induction, or $\frac{1}{.4\,\pi} = .7959$ ampere-turns, so as to maintain the 16,000 gausses in an air gap of even 1 millimetre would require $.1 \times .7959 \times 16{,}000 = 1273.44$ ampere-turns in addition to the 287 required by the iron. It will be seen from this that it is impracticable to maintain high densities of induction in the air gaps, even when they are narrow, and when it it is required to pass a considerable flux through an air gap, the poles are usually extended laterally so as to increase the cross section and reduce the density. As a matter of fact the lines of induction would not go straight across even a gap of one millimetre, but would bulge somewhat at the edges, so reducing the average density somewhat, but the ampere-turns for producing a given *density* of flux in the air gap would thereby be increased, although those necessary to produce a given amount of flux, or a given density in the cores, are diminished.

Given Ampere-Turns to Find Proper Current.

14. So far we have only considered the ampere-turns necessary to accomplish a given result, but another question of quite as great importance is, given the ampere-turns, how many amperes and how many turns shall be used? The answer to this question depends upon several things : upon the voltage to be used, the space on the magnet allowed for winding the wire, the amount of heat that can be gotten rid of, the amount of current available in those cases where the magnet is to operate with a feeble current and conditions pertaining to special cases. If the magnet is to be operated upon a constant potential we have a definite starting point for our calculations. Suppose for example that the E. M. F. is 1 volt and the magnet core is wound with 150 turns of wire which

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have a resistance of 1 ohm; there are of course then 150 ampere-turns on the magnet. Now suppose the turns increased to 300, the resistance is 2 ohms and the current ½ ampere, but the ampere-turns are still 150. It is evident from this that the ampere-turns are not altered by putting on more wire so long as the size of the wire and the length of a turn remain the same, because the amperes are reduced in exactly the same ratio as the turns are increased. But when we consider the power used to maintain the magnetism, the case is very different; for by Joule's law the power is $p = I^2 R$ which in the first case gives $1^2 \times 1 = 1$ watt and in the second case $(\frac{1}{2})^2 \times 2 = \frac{1}{2}$ watt. In other words the power consumed is inversely proportional to the number of turns used. Of course in winding layer after layer on a magnet core, the length of a turn keeps increasing, so that the foregoing statements have to be somewhat modified, but in this case we take the length of a turn midway between the innermost and the outermost ones and call it the mean turn. Then the total length of wire on the spool may be found by multiplying the number of turns by the length of the mean turn, and the number of turns on the spool only affects the ampere-turns at constant voltage in the same degree that it affects the length of mean turn, and it is still true that the more wire is wound on, the less power is consumed in maintaining the magnetism. Where the economy of power is the important consideration more wire may be used than otherwise, but the usual course is to design a magnet which is to be constantly excited, with a view to keeping the heating of the wire by the current within assigned limits, and at the same time to keep within reasonable limits of size. The subject of heating will be treated presently, but first the general relations between winding and magnetism will be investigated more fully.

Relation of Ampere-Turns to Wire Space.

15. We have just seen that with a given length of mean turn and constant voltage, the ampere-turns are constant whatever the number of turns; but it is usual to provide a certain space for the winding on a magnet, and if this space be wound full, the number of turns in the space depends upon the size of the wire. That is, allowing the same percentage of the total space to be occupied by

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insulation and interstices between the wires, whatever the size or guage number of the wire, the length of the wire, and consequently the number of turns that can be wound in a given space, is inversely as the cross section of the wire. The resistance of the coil or spool is therefore proportional to the square of the number of turns, the current at a given voltage inversely to the square of the number of turns, and the ampere-turns inversely to the number of turns. Suppose for example one spool was wound with No. 20 B & S guage and an exactly similar spool with No. 23; the cross section of No. 23 being one-half that of No. 20, the number of turns will be twice as great, the resistance four times as great, the amperes one-fourth as great and the ampere-turns one-half as great in the second coil as in the first. The power absorbed at constant voltage is of course proportional to the current, that is inversely to the square of the number of turns, but as the ampere-turns are inversely proportional to the number of turns, the power per ampere-turn is inversely proportional to the number of turns, as was found to be the case when more or less turns of a given sized wire were used. From the foregoing relations the windings of a magnet of one voltage may be calculated, if those for another voltage are known. For example to double the working voltage keeping the ampere-turns the same, use a wire three gauge numbers smaller, (B. & S. gauge only,) that is of half the cross section, which will give twice the turns, four times the resistance, and at the double voltage one-half the current, or the same ampere-turns as before. In general this would mean that the number of turns should be proportional to the voltage, or the cross section of the wire should be inversely proportional thereto.

These are the principal relations for magnets of one size, but there are other important relations between magnets of different sizes but of the same model or design. We have seen that in a magnetic circuit of a given quality of iron, the value of the induction $\mathfrak{B}$ depends upon the number of ampere-turns per centimetre of length of the circuit, and upon nothing else. If therefore we increase the cross section of the iron without altering the length of the magnetic circuit, we simply increase the total magnetic induction (webers,) proportionally, without altering the density, so as long as there is room to put more iron through the coil, more in-

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duction may be obtained without increasing the ampere-turns. Ordinarily the winding of magnets fits the cores snugly, so that in order to increase the size of the cores the size of the coils must be increased also. If all the dimensions of magnet be increased proportionally n times, the magnetic circuit is increased n times in length, and therefore requires n times the former ampere-turns to magnetize it to the former density, but a turn requires n times the former length of wire, so with the same current, n^2 times the former length of the wire will be required. But the cubical space for wire will be n^3 times the former space, so the cross section of the wire may be increased n times, which will give the wire n times the former resistance, or for the same current and ampere-turns n times the former power will be consumed. It thus appears that large magnets are relatively more economical of power than small ones, for the larger magnet with n times the power gives n^2 times the total induction, the relative volume of the winding being the same as in the smaller one, so if it be required to make the smaller magnet relatively as economical of power as the larger one, the relative volume of the winding must be increased.

Room Occupied By Insulation.

16. We have assumed that the insulation occupies the same relative amount of space as compared with the copper in all sizes of wire, which is not quite true, especially in the smaller sizes. The table on page 52 shows the diameters of bare wire, and also the diameters of the same wires with single silk and cotton covering. These diameters cannot be relied upon as absolutely correct, but represent pretty accurately the practice of the best manufacturers. In winding large magnets, such as the fields of dynamo machines, the amount of wire of any given size that will go in a given space is capable of calculation with considerable accuracy, for it is comparatively easy to keep the layers regular and also to wind exactly the calculated number of wires in a layer. But in small magnets, with which we are here more particularly concerned, and which are frequently wound with very fine wire, the case is quite different. It is impossible to keep the layers perfectly regular where the winding is many wires deep, if each layer is wound directly on the preceding

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one, so it is customary to insert a layer of stiff paper at intervals between the layers, so as to make a fresh start every time the winding begins to show signs of getting lumpy or irregular. This is when great care is taken in the winding, but in much commercial work it is not possible to bestow so much care on the winding, in view of the price for which the finished product must be sold, and in such work the winding is sometimes very irregular, and two magnets which are intended to be exactly alike may vary 15 per cent. or 20 per cent. in the amount of wire on the same sized spools. It is therefore necessary to allow more space for insulation with fine wire, than would appear necessary from merely inspecting the table, but this extra allowance is not a very definite quantity and depends upon several things, such as the uniformity of the insulation, the care with which the wire is wound and the frequency with which it is necessary to introduce the paper between the layers. The best that can be done in such cases, is to make an approximate calculation as to the number of turns of wire that will go in a given space, or of space required for a given number of turns of wire. Outside of these irregularities, due to the variable insulation space, the windings of a magnet can be calculated with a considerable degree of accuracy, for the diameter of any given sample of wire can be measured with a micrometer, even if it is not a gauge size, whereas the diameter over the insulation cannot be measured with much accuracy even with a micrometer, on account of the compression of the insulation. A much more accurate way to find the virtual diameter over the insulation, (that is the room taken up by the wire in actual work,) is to wind a layer of the wire on a smooth round stick and count the number of turns to an inch of length. This method gives a fair average if there are irregularities in the insulation, and it shows just how much the insulation will compress in winding.

Heating and Other Limiting Conditions.

17. The usual method of estimating the heating of the wire by the current is very simple. Under ordinary conditions it is assumed that one square inch of surface of the magnet coil will radiate heat amounting to one watt of power when it is one hun-

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dred degrees Fahrenheit warmer than the surrounding atmosphere. Therefore the watts lost in the magnet multiplied by one hundred and divided by the square inches of radiating surface, equal the degrees Fahrenheit of rise of temperature. The internal temperature will of course be somewhat higher than this, the amount of the excess depending upon the depth of the winding. The actual temperature depends on so many things that it is practically impossible to calculate it accurately, and the foregoing method seems to give about as good results in practice as any other, so it is very generally used. Heating is only taken into consideration in the design of magnets which are to carry current continuously for considerable periods. In many classes of work for which small magnets are used, the heating is altogether negligible; such, for example, as telegraph, telephone and bell magnets. On the other hand there are other magnets, such as those used in arc lamps, which carry a current for hours, and sometimes for days at a time, besides which they are exposed to a high temperature from the arc. The magnets (exclusive of dynamo field magnets) in which the heating is unimportant are largely in the majority. In the design of such magnets the principal points to be considered are the strength of magnetism required and the resistance, where direct currents are used, and in addition to these self-induction and impedance where alternating currents are used; or where the magnet must act very quickly, the time constant. These effects will be investigated after finishing with the simpler parts of the calculation.

Winding a Magnet for a Given Voltage.

18. Suppose it were required to wind the magnet described in art. 12 to operate on 10 volts, and suppose further that the outside diameter of the spools must be not over $1\frac{1}{4}$ inches, their outside length $1\frac{7}{8}$ inches, so that allowing a spool with heads $\frac{1}{8}$ inch thick and a shell around the core $\frac{1}{16}$ inch thick, there is a space $1\frac{5}{8}$ inches long by $\frac{3}{8}$ inch deep on each spool, in which to wind the wire. The inner diameter of the winding being $\frac{1}{2}$ inch and the outer diameter $1\frac{1}{4}$ inches, the mean diameter is $\frac{7}{8}$ inch and the length of mean turn $\frac{7}{8}\pi = 2.74889$ or practically 2.75 inches. The ampere-turns required were found in art 12 to be 287, so assuming 1000 turns the current

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required is .287 ampere, which means at 10 volts, 34.84 ohms. At 2.75 inches per turn 1000 turns make 2750 inches, or 229.17 feet, which gives 34.84÷229.17=.1564 ohms per foot. Consulting a table of resistances we find that No. 33 British gauge is the nearest size, and that when single cotton covered it lays 79.16 turns per inch. This gives 149 turns per layer on each spool, and allows for 29 layers if the wire can be wound with perfect regularity, which makes in all 4321 turns per coil or 8642 turns in all. This will of course reduce the current in a corresponding degree, but not the ampere-turns, for the length of mean turn is what we have assumed because the spools are wound full. Of course the calculated number of turns cannot be wound on and we might allow 10, 15, or even 20 per cent. if necessary to provide for paper between the layers, without materially affecting the ampere-turns, especially if the papers are about equally distributed, for then the length of mean turn will not be altered, provided both internal and external diameters are unaltered. The size of wire taken is too small and consequently of too high resistance, so the ampere-turns are too small. The resistance of No. 33 British gauge at 75° Fahrenheit is .1647, which reduces the ampere-turns about 5 per cent. If we take No. 31 American gauge the resistance being at 75° Fahrenheit .1272 ohms, the ampere-turns will be about 22 per cent. greater than those found by the calculation to be necessary, but at 120° the excess will be only 12 per cent.

As in practice it is more important that a magnet should be plenty strong enough than that it should be of an exact strength, No. 31 American gauge should be used. This calculation shows that with a given wire space and a definite percentage of that space occupied by insulation, the ampere-turns at constant voltage depend upon the resistance of the wire per foot and upon nothing else. So long as the copper is of the same quality the resistance per foot of the wire depends on its diameter only. If then it be necessary to adjust the ampere-turns upon a given magnet to a value between the values given by two regular gauge numbers, it may be accomplished in several ways. The larger of the two gauge numbers should be used, which will make the excitation too great, and the length of mean turn may be increased by starting with a larger internal diameter, or by putting sufficient paper between the layers,

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increasing the external diameter and with it the length of mean turn; or where accuracy is required, it is much better to have an adjustable external resistance. Control by external resistance is nearly always resorted to in the shunt fields of dynamo machines, which are by far the most important class of magnets in which an exact degree of excitation is required. In the vast majority of magnets, the exact strength is not of so much importance as strength enough, and in many magnets, such as ordinary telegraph and bell magnets, the operation consists of alternately attracting and releasing the armature, and so long as the armature is attracted with sufficient force, the exact amount of the force is unimportant. But even where the exact strength of the magnet is of importance it is not worth while to take a great deal of pains to have the ampere-turns exactly right without external adjustment, for even if correct at one temperature, the variation of the resistance of copper with variations of temperature is considerable, and if the temperature varies much, the adjustment of the ampere-turns will be destroyed.

Hysteresis.

19. Besides this there is another phenomenon, a property of the iron itself, which interferes with the exactness of any permanent adjustment of the ampere-turns on a magnet to produce a field of given strength. This property is called hysteresis, or magnetic retentiveness, and may be described as the tendency of iron to persist in any magnetic state once acquired. That is, the cores of a magnet when first made are unmagnetized, and when the magnetizing force is applied they tend to retain their unmagnetized state, and therefore at any given excitation the permeability is lower than it would otherwise be. But if the core be very strongly excited and then the magnetizing force gradually reduced, the state of magnetization tends to persist in the iron, and at any given excitation the permeability and consequently the induction is greater than at the same excitation before, or when the magnetizing force was rising. In Fig. 14 may be seen the different values of the induction $\mathcal{B}$ with the same magnetizing force $\mathcal{H}$ according to the previous state of magnetization of the iron. Starting from the point o in the first place, the induction follows the middle curve

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in the figure up to the upper right hand corner of the curvilinear figure, where $\mathcal{B}=11000$ for $\mathcal{H}=7$, then as the magnetizing force $\mathcal{H}$ is diminished, the induction follows the law represented by the left hand curve, until when $\mathcal{H}$ reaches 0 $\mathcal{B}$ still retains a value of 9000. In order to bring $\mathcal{B}$ down to zero, it is necessary to make $\mathcal{H}$ almost -2; that is the magnetizing force has to be reversed and brought to a considerable negative value before the magnetism returns to zero. Continuing the process, $\mathcal{B}=-11000$ when $\mathcal{H}=-7$, and then when $\mathcal{H}$ is brought to zero and finally made positive

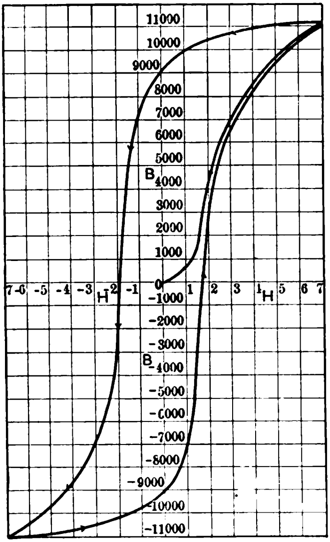

FIG. 14.

again, the corresponding values of $\mathcal{B}$ are found on the right hand curve. This diagram is taken from one of Ewing's tests of a very soft iron ring. In other specimens of iron or steel the loop may be wider or more open, or it may be narrower or more close, but in every case there will be some loop and the curve of letting down the magnetism will never be quite the same as that of raising. Hence it is evident that the strength of the field of an electromagnet can-

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not be determined with perfect accuracy from the exciting ampere-turns, and where it is necessary to adjust the field to an exact figure, some means of adjusting the ampere-turns such as a rheostat is always used.

Every time the polarity of a magnet core is reversed some electrical energy is converted into heat, and raises the temperature of the core. The heating seems to be due to a sort of inter-molecular friction, and cannot be gotten rid of by any known means; the only remedy is make the cores of magnets which are to be used on alternating currents of iron which shows by actual test the least amount of this loss. This conversion of the energy of the current into heat is usually called hysteresis loss, inasmuch as in ordinary circumstances it is proportional to the area of the hysteresis loop; but if the iron be subjected to vibrations during the magnetizing process, the loop may be made to collapse entirely, so that the ascending and descending curve are the same, yet there is still energy converted into heat in the process of reversal. This heat is expressed by the following law due to Steinmetz. Let $W_H =$ loss of energy per cycle, in ergs (C. G. S.) units, for every cubic centimetre of the iron, $\mathfrak{B} =$ maximum value of the induction and η (the Greek letter called eta).= the co-efficient of hysteresis, then

$$W_H = \eta \mathfrak{B}^{1.6},$$

or the dissipation of energy is proportional to the 1.6 power of the induction. The co-efficient η in iron varies from .09124 to .0055, a fair mean being .0033 for good annealed sheet iron or steel. In grey cast iron, η averages .013; it varies from .0032 to .028 in cast steel, and reaches .08 in hardened tungsten and manganese steel.

Self-Induction.

20. When the circuit of an excited electromagnet is suddenly ruptured, there is usually considerably more spark or arc produced than would occur upon the rupture of the same circuit if the magnet were not connected in. This effect was called by Faraday the extra current of breaking the circuit, and is now called the self-inductive current, or in shop phraseology, the "kick" of the magnet. The cause of this phenomenon is as follows:

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When the magnet is excited there is a certain amount of field constantly maintained, but as soon as the circuit is opened the current tends to stop, and were it not for this very phenomenon it would actually stop. But as the current decreases the magnetic field also decreases, and this decrease in the field produces an electromotive force in the same directíon as the existing current. By reference to Fig. 6 it will be seen that the lines of magnetic induction and the circuit are linked together like the links of a chain. It is an experimental fact that the number of lines so linked with a circuit cannot be altered without producing an E. M. F. so long as the alteration is going on. The law of the E. M. F. is this: if the field is gaining or losing at the rate of 10^8 webers per second, (that is one hundred million webers,) then there will be one volt of induced E. M. F. in each turn of the winding. The more suddenly the current is stopped in the winding of an ordinary magnet the more suddenly the core is demagnetized, and the higher the inductive E. M. F. But the inductive E. M. F. tends to maintain the current, so that opening the circuit will never instantly stop the current. If it were possible to instantly demagnetize the core, the E. M. F. would be infinite and would of course perforate the insulation. As a matter of fact there is danger of perforating the insulation of any large magnet having many windings upon it, such as the shunt field magnet of a large dynamo, by too suddenly stopping the current, unless it is provided with some protective device.

When the circuit is closed there is an inductive E. M. F. just the same, but in this case it tends to hold back or hinder the flow of current. This counter E. M. F., as it is then called, can never be equal to the direct E. M. F., for it would then stop the flow of current, but before the current stops, and in fact as soon as it stops increasing, the counter E. M. F. stops altogether. This counter E. M. F. was called by Faraday the extra current of closing the circuit. In modern phraseology this resistance to change in the current strength is called self-induction or inductance; it is measured in henrys, the henry being defined thus: an inductance of one henry gives rise to an E.M.F. of one volt when the current varies at the rate of one ampere per second. Inductance is represented by the letter L, the inductance of a particular magnet being equal to the product of the turns of wire by the strength of field, divided by the current, when

the units are all in one system, but as amperes and henrys belong to the practical system and webers to the C. G. S. system, the equation with these units is $L = \frac{\Phi N}{I \times 10^8}$. In a coil of wire without iron L is a constant, but where there is an iron core L is not a constant, because, owing to the variable permeability of the iron, the magnetic flux per ampere is variable. The magnet calculated in art. 12 has a cross sectional area of .11045 square inches or .7126 square centimetres, which means a flux Φ of 1140 webers for $\mathfrak{B} = 1600$ gausses, and with 8642 turns of winding and .0332 amperes exciting current we have

$$L = \frac{\Phi N}{I \times 10^8} = .299 \text{ henrys.}$$

21. In magnets which are to operate quickly the effects of the inductance must be considered. When the circuit is first closed the current does not at once take its final value as determined by Ohm's law, $I = \frac{E}{R}$, but at the end of any short time t, it may be expressed by what is known as Helmholtz's law,

$$I = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

in which e equals the base of the Napierian logarithms 2.7182818. The ratio $\frac{L}{R}$ is called the time constant of the magnet. If $\frac{L}{R}$ be substituted for t in the foregoing formula then it reduces to

$$I = \frac{E}{R}\left(\frac{e-1}{e}\right) = \frac{E}{R}.634.$$

That is the time constant of a magnet is the time it takes for the current to attain .634 of its final or steady value. The time constant may be decreased by either decreasing the inductance or increasing the resistance. It may at first seem strange that increasing the resistance will make a magnet work

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more quickly, but it must be borne in mind that if the resistance be increased, in order that the final value of the current shall be the same, the E. M. F. must be increased in the same ratio, and the counter E. M. F. remaining unchanged, it is a smaller percentage of the total obstruction to the passage of the current, and therefore the current reaches a given percentage of its final value sooner.

The tendency of a magnet to "spark" on breaking the circuit, is made use of in the coils that are designed for gas lighting. The inductance is intentionally made high, and the magnetic circuit contains an air gap to assist in the sudden demagnetization of the core. By simply inserting the winding of such a magnet in the circuit of a battery of two or three cells, sparks of sufficient size to light gas are easily obtained. The sparks are many times larger than those from the same circuit without the magnet. All that is necessary to produce the sparks is to have some mechanism to rupture the circuit suddenly.

Alternating Currents.

22. With alternating currents the effect of the inductance is to reduce the amount of current that flows through the magnet, not only momentarily but permanently. The subject of alternating currents is too extensive and too complicated to treat in this article, so only their most important relations to electromagnets will be here mentioned. In alternating currents the E. M. F. and the current both alternate, and moreover they alternate the same number of times in a second, but they do not always alternate simultaneously. That is one may be ahead of the other just as two persons who are walking together at the same speed and with steps of equal length may yet be out of step with one another. They are then said to be out of phase, the one which arrives at a given phase the sooner is said to lead and the other to lag. The word phase is used in its ordinary English sense, and means any particular instantaneous state, such as zero, maximum, &c. One of the effects of inductance is to make the current lag behind the E. M. F., for so long as the current is increasing, the inductive E. M. F. holds it back, and so long as it is diminishing, the inductive E. M. F. tends to keep it go-

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ing, so delaying it at all phases. Another effect is to diminish the total current which passes, for when the current arrives at its maximum the inductive E. M. F. is for a moment zero and the value of the current at that instant is just what it would be at that instant were there no inductance in the circuit,—namely the current due to the E. M. F. at that instant,—but as the E. M. F. is past its maximum, the maximum value and therefore the mean value of the current is less than when there is no inductance. Inductance has then the effect of increasing the resistance of the circuit to alternating currents, the increased resistance being called effective resistance or impedance. The impedance is found thus: a double alternation, that is from positive to negative and then back to positive again, is called a cycle, and the number of cycles per second is called the frequency and denoted by the letter N; the impedance is then $Z = \sqrt{R^2 + (2\pi LN)^2}$.

It is obvious from the foregoing that a given magnet will be less strongly excited on an alternating current circuit of a given voltage than on a direct current circuit of the same voltage, but the difference in the excitation depends first on the frequency, and then on the construction of the magnet itself. Owing to the fact that the magnetism in the iron is not strictly proportional to the exciting current, as has been remarked, the inductance is variable and the fact that inductance alters the current, causes it to alter itself also, so that it is not a simple problem to tell beforehand just what the value of the current will be. However this can be done if there be a curve drawn showing the magnetic flux for each current strength.

It is more difficult to excite a magnet strongly with alternating currents than with direct, because every attempt to compensate for the effects of inductance by putting on more turns, increases the inductance itself in a higher ratio; while reducing the resistance by using larger wire requires more room. Electromagnets for alternating currents require more care in designing than for direct currents, and it is found in practice better to use lower densities of induction for several reasons. The so called hysteresis losses are thereby reduced, and the power consumed directly in the excitation is relatively less. The cores of an alternating current magnet must be built up of thin laminae or wires insulated from

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each other, in order to prevent the generation of eddy currents in the iron. With a solid core these eddy currents are sometimes very serious, wasting much power and heating the cores to such an extent that they cannot be used continuously for any length of time.

Traction.

23. The lifting power or traction of a magnet when the poles are in actual contact with the keeper, depends upon two things, the area of the poles and the intensity of the induction: it is proportional to the former and to the square of the latter. This proportionality to the square of the induction accounts for some anomalous peculiarities in the way that the keeper of a magnet holds fast to the poles. If the pole faces are perfectly true and flat and the face of the keeper the same, the keeper is actually held with less force than when the pole faces are very slightly convex. Or again, if the keeper be slid to one side until only its sharp edge and that of the poles are in contact, it will be found to adhere more firmly than when placed squarely and centrally on the poles. In general a magnet holds tighter to a slightly uneven surface than to one which perfectly fits the poles. The reason is that when the area of contact is decreased, the intensity of the induction through the remaining contact is increased, by the crowding together of the lines of induction, and as the traction is proportional to the product of the area and the square of the intensity of the induction, so long as there is sufficient crowding of the lines so that the square of their intensity increases more than the area is diminished, the traction is increased by reducing the area of contact.

The amount of the traction is usually determined by the formula $T=\frac{\mathfrak{B}^2}{8\,\pi}$, in which T is the traction per square centimetre expressed in dynes: to express the traction in grammes, this figure is of course divided by 981, or for pounds avoirdupois per square inch it should be divided by 69090. This formula is correct for the force required to separate the halves of a straight bar magnet cut in the middle, if the winding is also in halves and these halves separate at the same time as their respective halves of the

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core, and if further the winding fits the core closely. It is also correct for the separating force when the magnetism is residual as in the case of a permanent magnet. In other cases, for example where an ordinary keeper is pulled away from a magnet, the formula is not strictly accurate on account of the keeper being attracted partly by the core of the magnet and partly by the current in the winding directly. However the attraction exerted by the coil is usually small as compared to that exerted by the core, and the formula is not very much in error.

The attraction between the two parts of the iron is always $2\pi\mathfrak{I}^2$ dynes per centimetre, $\mathfrak{I}$ being the intensity of magnetization, that is the number of units of free magnetism per square centimetre. But $\mathfrak{B}=4\pi\mathfrak{I}+\mathfrak{H}$ so when $\mathfrak{H}=0$, that is when there is no magnetizing force, $2\pi\mathfrak{I}^2=\frac{\mathfrak{B}^2}{8\pi}$, which is evidently correct, as there is no attraction except between the two parts of the iron. When $\mathfrak{H}$ is not equal to zero, that is, when the magnetism is not residual, there is a force between the coil and the part of the iron that is moved away from the coil equal to $\mathfrak{H}\mathfrak{I}$ dynes per square centimetre, so that the whole force of separation is $2\pi\mathfrak{I}^2+\mathfrak{H}\mathfrak{I}$. When there is a coil on each part of the magnet and both parts of the magnet and both coils are just alike, there are two of these $\mathfrak{H}\mathfrak{I}$ forces, because each coil attracts the other part of the iron, but as in this case $\mathfrak{H}$ represents the intensity of the magnetizing force of the whole coil each half now attracts the other part of the iron with a force of $\frac{\mathfrak{H}\mathfrak{I}}{2}$ and both forces together equal $\mathfrak{H}\mathfrak{I}$. The two coils attract each other with a force of $\frac{\mathfrak{H}^2}{8\pi}$ per square centimetre, so the whole force is $2\pi\mathfrak{I}^2+\mathfrak{H}\mathfrak{I}+\frac{\mathfrak{H}^2}{8\pi}$, which may be written

$$\frac{1}{8\pi}(16\pi^2\mathfrak{I}^2+8\pi\mathfrak{H}\mathfrak{I}+\mathfrak{H}^2)=\frac{1}{8\pi}(4\pi\mathfrak{I}+\mathfrak{H})^2=\frac{\mathfrak{B}^2}{8\pi}$$ per square centimetre, so in this case also the traction is proportional to the

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square of the intensity of the induction. If the coils be loose upon the cores so that their areas are sensibly greater than those of the cores, the whole force of separation is greater than that given by the equation, but in practical cases the error is usually small. In all cases the attraction between the iron parts is $2 \pi \mathfrak{J}^2$ per square centimetre.

24. The question is sometimes asked, "Why is the electromagnet in a telephone also permanently magnetized?" The reason is because a telephone so made is more sensitive to small changes in the magnetizing current, and the reason for this is found in the fact discussed in the last paragraph, that the traction of the magnet is proportional to the square of the intensity of the induction. Suppose, for example, that a certain small current is capable of producing in the field of the telephone magnet, an intensity of induction, $\mathfrak{B}=1$ gauss: the pull on the diaphragm is then proportional to $1^2=1$. Next suppose the telephone had a permanent magnet giving a field where $\mathfrak{B}=1000$ gausses and the current increased it to 1001 gausses. The pull in this telephone would be, before the current flowed, $1000^2=1000000$, and after the current flowed $1001^2=1002001$ times as great as in the first case. As the sound in a telephone depends not upon the force with which the diaphragm is attracted, but upon the variation of that force, take the differences and we have $1002001-1000000=2001$ and $1-0=1$ as the relative sensitivenesses of the two telephones. Or in other words the sensitiveness of the telephone to small variations of current is proportional to twice the value of $\mathfrak{B}$ in the field of the permanent magnet, provided the permeability remains the same. The permeability of a steel magnet is of course very much less than that of a soft iron core, so that a given current actually makes less change in the value of $\mathfrak{B}$ in the steel than in the iron, yet notwithstanding this, the variation in the *pull* on the diaphragm for a given change in the value of $\mathfrak{B}$ is so very much greater where the field is already strong, that the permanent magnet telephone is found in practice to be much the more sensitive instrument.

TOWNSEND WOLCOTT.

BROOKLYN, N. Y.
June, 1900.

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THE ELECTRO MAGNET.

PART II.

BY A. E. KENNELLY.

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APPENDIX.

ON THE RELATIVE VALUES OF THE WINDINGS OF ELECTROMAGNETIC COILS.

An electromagnetic coil, whether used as an induction coil or as a magnet coil, is an assemblage of turns of insulated wire in a definitely prepared space—a winding space surrounding the core. If the wire be carelessly wound, particularly when it is of small diameter, much of this winding space will be wasted. On the contrary, if the wire be carefully wound, the winding space will be more nearly filled with copper, or utilized. An ideally perfect winding would have no interstices between adjacent layers, or between adjacent turns, and the thickness of the insulation covering on the wire would also be vanishingly small. Such an ideal wire might be of square cross-section, and with indefinitely thin insulation. In the ideal case, practically all of the winding space would then be occupied by the conductor and there would be practically no waste or non-conducting space. Such a condition being, however, quite impracticable, the ratio of the space in a winding occupied by conductor to the total space occupied, may be called the *coefficient of space utilization of the coil*, and we may denote it by the symbol u. For the ideal winding $u = 1$ or 100%. In practice u may be as high as 0.75 with very coarse round wire in field-magnet windings, representing three-fourths of the winding space filled by copper, while in fine-wire coils it may be as low as 0.3, depending upon the thickness of insulation and the regularity of winding.

Where there is no restriction upon the depth of coil winding, the result of a small u may be merely an increase in the external diameter of the coil in order to apply a given number of turns. This will be accompanied, however, by some increase in the length of the wire; so that it is correct to say that a relatively small value of u is always necessarily attended by an expense of some sort. If,

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however, the winding space be limited, the importance of the coefficient u becomes considerably increased. In such cases a relatively large value of u (assuming, of course, that the insulation of the wire remains sufficiently good) is as important as the conductivity of the conductor. This is evident since if a given winding space is occupied by 1000 turns of wire with a coefficient of $u = 0.3$ and a similar winding space is occupied by 1000 turns with the coefficient of $u = 0.6$, the cross-section of the wire in the latter case will be just double that in the former, or the winding will have half the resistance. In other words, a doubled coefficient has the same effect as doubling the conductivity of the wire. Consequently, every improvement which is made in the methods of winding coils, whereby, without sacrifice of insulation, an increase of space-utilization coefficient is obtained, is equivalent to a corresponding improvement in the conductivity of the conductor, al hough the full value of the improvement may only be required or availed of in particular cases; as, for example, where the winding space is restricted, and the winding has to be confined to fixed limits.

The arithmetical analysis which follows shows that where a coil has a given internal diameter and interflange length, but has the external diameter left variable, the influence of an improvement in winding and an increase in u does not have much effect either in size or in cost of the winding, unless the internal diameter is comparatively small. In other words, while an improvement in u always reduces, to some extent, the length of wire or size of coil or the resistance for a given number of turns, and, therefore, improves the coil electrically, the amount of the improvement depends upon the internal radius and length of the coil. The improvement will be greater as the internal diameter is reduced. With a negligibly small internal diameter, the length of wire for a given number of turns would vary inversely with u. With a large internal diameter the improvement due to increasing u tends to become inappreciable.

Where, however, the external diameter of the coil instead of being left free, is fixed, together with the internal diameter, and interflange length, thus reducing to the condition of fixed coiling space, then it is shown that the length, turns, mass and resistance of the winding which can be put into this space increase directly

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with *u*; so that a 16% improvement in *u* means 16% more turns weight, feet and ohms in the winding, if the size of wire remains unchanged. If the wire is varied in size, so as to maintain constant resistance, then the number of turns increases as the square root of *u*; so that a 16% improvement in *u* represents an increase in the number of turns of about 8% with the same resistance, assuming that the proper size of wire can be drawn. The mass and volume of the wire in the winding will, of course, increase in proportion to *u*. The improved winding takes the same current from constant-pressure continuous-current mains, but will develop increased ampere-turns or magnetomotive force proportionally to the square root or *u*; or about 8% more ampere-turns for 16% improvement in *u*. The reactance of the winding for alternating currents of given frequency will be proportional to *u*; consequently, an increase of alternating-current pressure at the terminals in the ratio of *u* would give the same current-strength through the coil, but would increase the M.M.F. in the ratio of the square root of *u*.

If in the last case the number of turns be kept constant instead of the resistance, the resistance will vary inversely as *u*. The advantage of an increase in *u*, having a fixed winding space, may be taken either wholly in an increased number of turns, keeping the same resistance, or in a diminished resistance, keeping the same number of turns, or partly in increased number of turns and partly in diminished resistance.

A. E. K.

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APPENDIX II.

Let R = the winding radius, or internal radius of coil (cms.)

D = the winding diameter = $2R$ or internal diameter of coil (cms.)

R' = the external radius of the finished coil (cms.)

D' = the external diameter = $2R'$ of the finished coil (cms.)

R_m = the mean radius = $\frac{R+R'}{2}$ of the finished coil (cms.)

D_m = the mean diameter = $\frac{D+D'}{2}$ of the finished coil (cms.)

H = the depth of winding = $R' - R$ of the finished coil (cms).

L = the interflange length of the finished coil (cms.)

S = the sectional area HL of the finished coil (sq. cms.)

V = the volume of the winding, or space occupied (c.c.)

r = the radius of the wire (cms.)

d = the diameter of the wire = $2r$ (cms.)

λ = the length of the mean turn = $2\pi R_m$ (cms.)

l = the length of the wire (conductor) (cms.)

n = number of turns of wire (conductor) ~~(cms.)~~

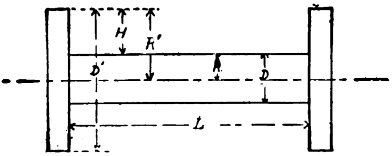
s = the sectional area of wire (conductor) (sq. cms.)

δ = the specific gravity of the wire (conductor).

$\underline{R}$ = the resistance of the wire (conductor) (ohms).

ρ = the resistivity of the wire (conductor) (ohms-cms.)

u = the coefficient of space utilization = $\frac{ns}{S} = \frac{ls}{V}$



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Properties of Fixed Winding Spaces (L, R and R' constant) and a Fixed Size of Wire (d constant.)

The length of the wire l, which can be wound into the space is

$$l = 2\pi n R_m \text{ cms.}$$

$$= \frac{V}{s} u \qquad \text{cms.}$$

or is proportional to u.

Example:

$$\begin{aligned} \text{Let } L &= 5.0005 \text{ cms. } (1.96875'') \\ D &= 1.0922 \text{ cms. } (0.430'') \\ D' &= 2.30187 \text{ cms. } (0.90625'') \\ d &= 0.014227 \text{ cms. } (0.0056'' \text{ No. 35 A.W.G.}) \\ \text{Then } V &= 16.125 \text{ c.c. } (0.984 \text{ cub. in.}) \\ s &= 1.5897 \times 10^{-4} \text{ sq. cms. } (3136 \text{ cir. mils}) \end{aligned}$$

$$\text{and } l = \frac{16.125}{1.5897 \times 10^{-4}} u = 101432\, u.$$

With $u = 0.4445$ $l = 101432 \times 0.4445 = 45{,}086$ cms. $= 1479$ ft.
" $u = 0.5164$ $l = 101432 \times 0.5164 = 52{,}380$ cms. $= 1718.5$ ft.

The number of turns of wire in the coil is

$$n = u \frac{S}{s} \text{ and increases directly with } u.$$

For the case considered

$$S = 3.0245 \text{ sq. cms.}$$
$$s = 1.5897 \times 10^{-4} \text{ sq. cms.}$$

$$n = \frac{3.0245}{1.5897 \times 10^{-4}} = 19025\, u.$$

With $u = 0.4445$ $n = 19025 \times 0.4445 = 8456.7$ turns.
" $u = 0.5164$ $n = 19025 \times 0.5164 = 9824.6$ turns.

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The mass of wire in the coil is

$$M = V\,\delta\,u \qquad \text{grammes,}$$

and increases proportionately to u.

In the case considered

$$V = 16.125 \text{ c.c.}$$
$$\delta = 8.89$$
$$M = 143.36\,u \qquad \text{grammes.}$$

With $u = 0.4445$ $\quad M = 63.72$ grammes.
" $\quad u = 0.5164$ $\quad M = 74.03$ grammes.

The resistance of wire in the coil is

$$\underline{R} = \frac{V}{s^2} \times \rho\, u$$

and increases directly with u.

In the case considered

$$V = 16.125 \text{ c.c.}$$
$$s = 1.5897 \times 10^{-4} \text{ sq. cms.}$$
$$\rho = 1.8452 \times 10^{-6} \text{ ohms-cm.}$$
$$\underline{R} = 1177.36\,u$$

With $u = 0.4445$ $\quad \underline{R} = 523.33\,\omega$
" $\quad u = 0.5164$ $\quad \underline{R} = 607.97\,\omega$

SUMMARY: In a given winding space, with a given size of wire, the number of turns, length, mass and resistance of the wire are all proportional to u. The reactance will be proportional to u^2, with an air core. Such a coil supplied with a given direct current strength will develop a magnetomotive force proportional to u, but supplied with constant direct pressure, the magnetomotive force will be independent of u, while the current strength will be inversely as u. In other words increasing u does not vary the magneto-motive force but obtains the same magnetomotive force with a reduced current strength.

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Properties of Fixed Winding Space and Variable Size of Wire (L, R and R' constant—d and u Variable).

For given resistance $\underline{R}$

The radius of the wire which will fill a given winding space is

$$r = \sqrt[4]{\frac{D_m\, S\, \rho\, u}{\pi\, \underline{R}}} \text{ cms.}$$

and increases with the fourth root of u.

In the case considered

$D_m = 1.697035$ cm. (0.668125").
$S = 3.0245$ sq. cms (0.66568 sq. in.)
$\rho = 1.8452 \times 10^{-6}$ ohm-cms.
$\underline{R} = 520$ ohms.

$$r = \sqrt[4]{\frac{1.697035 \times 3.0245 \times 1.8552 \times 10^{-6} \times u}{3.1416 \times 520}} = 0.0087259\, u^{\frac{1}{4}}$$

With $u = 0.4445$ $u^{\frac{1}{4}} = 0.81614$
$r = 0.0087259 \times 0.81614 = 0.0071249$ cm.
$d = 0.01425$ cm. $= 0.00561$" No. 35 A.W.G.

With $u = 0.5164$ $u^{\frac{1}{4}} = 0.84771$
$r = 0.0087259 \times 0.84771 = 0.007397$ cm.
$d = 0.014794$ cm. $= 0.00582$".

The sectional area of the required wire will vary as the square root of u. Increasing u 21% will increase the circular mils 10%.

The length of the wire which has the required resistance is

$$l = \sqrt{\lambda\, S\, \underline{R}\, \frac{u}{\rho}} \text{ cms.}$$

or varies as the square root of u.

In the case considered

$\lambda = 5.3314$ cms. (2.099")
$S = 3.0245$ sq. cms. (0.66568 sq. in.)
$\underline{R} = 520$ ohms.
$\rho = 1.8452 \times 10^{-6}$ ohm-cms.

$$l = \sqrt{\frac{5.3314 \times 3.0245 \times 520 \times u}{1.8452 \times 10^{-6}}} = 67{,}410 \sqrt{u}$$

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With $u = 0.4445$ $\sqrt{u} = 0.6667$ $l = 44942$ cms. $= 1474.5'$

" $u = 0.5164$ $\sqrt{u} = 0.71861$ $l = 48441$ cms. $= 1589.3'$

The number of turns of the wire which is required is

$$n = \sqrt{\frac{S R}{\lambda} \frac{u}{\rho}}$$

or varies as the square root of u.

In the case considered

$S = 3.0245$ sq. cms. (0.66568 sq. in.)

$\lambda = 5.3314$ cms. (2.099'').

$R = 520$ ohms.

$\rho = 1.8452 \times 10^{-6}$ ohm-cms.

$$n = \sqrt{\frac{3.0245 \times 520 \times u}{5.3314 \times 1.8452 \times 10^{-6}}} = 12{,}644 \sqrt{u}$$

With $u = 0.4445$ $\sqrt{u} = 0.6667$ $n = 8430$

" $u = 0.5164$ $\sqrt{u} = 0.71861$ $n = 9086$

The mass of the wire which is required is

$M = V \delta u$ grammes

and increases proportionately to u.

In the case considered

$V = 16.125$ c.c. (0.984 c. in.)

$\delta = 8.89$

$M = 16.125 \times 8.89 \times u = 143.35\ u.$

With $u = 0.4445$ $M = 63.72$ grammes.

" $u = 0.5164$ $M = 74.026$ grammes.

The volume of wire (conductor) which is required is

$V u$ c.c.

and increases proportionately to u.

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The reactance of the winding will be proportional to u.

When supplied with a given direct-current pressure, the current strength will remain constant; but the M.M.F. will be proportional to the square root of u.

Fixed Winding Space and Fixed Length of Wire or Number of Turns (u variable).

The resistance

$$R = \frac{\lambda n^2}{S} \frac{\rho}{u} = \frac{l^2}{S \lambda} \frac{\rho}{u}$$

or varies inversely as u.

An increase in u to the extent of say 11.1% will effect a diminution in the resistance of the winding to the extent of 10%, if the correct diameter of wire can be obtained.

The sectional area of the wire required for a given number of turns is

$$s = \frac{S}{n} u \quad \text{sq. cms.}$$

$$= \frac{V}{l} u \quad \text{sq. cms.}$$

The mass of the wire will be proportional to u.

The reactance of the winding will be constant.

The M.M.F. will be constant for constant current strength. For constant pressure, the current strength and M.M.F. will vary directly with u.

Constant Internal Dimensions, but External Diameter of Coil variable.

Constant size of wire and number of turns, u variable.

The external diameter

$$R' = \sqrt{R^2 + \frac{lr^2}{Lu}} \quad \text{cms.}$$

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In the case considered,

$R = 0.5461$ (0.215")
$l = 45{,}086$ cms. (1479")
$L = 5.0005$ (1.96875")
$r = 0.00711355$ cm. (No. 35, A.W.G.)
$u = 0.4445$

$$R' = \sqrt{(0.5461)^2 + \frac{45086 \times 0.00711355^2}{5.0005 \times 0.4445}}$$
$$= 1.153 \text{ cms.} = 0.453''.$$

If the internal radius R were vanishingly small R' would vary inversely as the square root of u, so that increasing u 21% would diminish the external diameter of the coil about 10%. As the internal radius R increases, the influence of a change of u is felt less and less, so that on a very large spool, with a moderate amount of wire or winding depth, the value of u is of no serious importance.

The number of turns is

$$n = \frac{uL}{s}\left(\sqrt{R^2 + \frac{lr^2}{uL}} - R\right)$$

With a vanishingly small internal radius the number of turns would increase with the square root of u; or,

$$n = \frac{r}{s}\sqrt{L\, l\, u}$$

but, as the internal radius increases, the gain in the number of turns through increase in u becomes less appreciable.

The volume of winding space for a given length of wire wouid always be inversely proportional to u.

Fixed Internal Radius and Interflange—Fixed Number of Turns of Same Size of Wire (u variable).

The length of the winding will be

$$l = 2\,\pi\,n\left(R + \frac{ns}{2uL}\right) \qquad \text{cms.}$$

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In the case considered

$$n = 8430$$
$$R = 0.5461 \text{ cm.} \quad (0.215'')$$
$$s = 1.5897 \times 10^{-4} \text{ sq. cm.}$$
$$L = 5.0005$$
$$u = 0.4445$$

$$l = 6.2832 \times 8430 \left(0.5461 + \frac{8430 \times 1.5897 \times 10^{-4}}{2 \times 0.4445 \times 5.0005} \right) = 44{,}900 \text{ cms.}$$

If R were vanishingly small, l would become

$$\frac{\pi n^2 s}{uL}$$

or would vary inversely as u, so that a 10% increase in u would represent a diminution in the length of wire for given turns, of about 9%. As R increases, however, the effect of u becomes less and less.

A. E. K.

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The Electro Magnet.

PART III.

By Richard Varley.

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Practical Calculations of Magnet Coils.

By Richard Varley.

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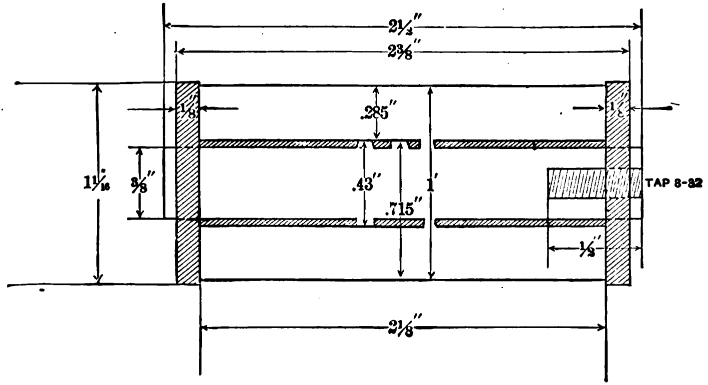
The Importance of Details.

The usual text-book information on the Electro-magnet is, as a rule, far too theoretical for the practitioner; the difficulties encountered in actual practice are rarely mentioned, and as a result the student who endeavors to design an Electro-magnet is disappointed to find his results do not compare favorably with his calculations.

These difficulties are caused by apparently small details usually regarded as being of little consequence, not only by the student but by the Manufacturer and Engineer as well, but which when considered show almost startling results.



In the above sketch is shown the winding dimensions of a bobbin, the core is three-eighths of an inch and the flange is one and one-sixteenth inches.

Before winding, the core is wrapped with two or three layers of paper and the winding is discontinued a little under one and one-sixteenth inches. The winding length being two and one-eighth inches, the student estimates 687 ohms as the amount of No. 35 B & S single silk covered wire that will be contained in the bobbin and is surprised to find only 567 ohms when finished, having lost over seventeen per cent. somewhere.

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When the bobbin was wound it appeared to be full whereas its true diameter was one inch and with ordinary spring calipers, the core to be wound on was three-eighths full, its exact value being forty-three hundredths, and as the amount of wire contained in the bobbin is proportional to $D^2 - d^2$, we obtain a value .985 equal to $(1.0625^2 - .375^2)$ in the first case and only .815 equal to $(1^2 - .43^2)$ in the second case, a difference of 17 + per cent.

Again if this particular wire is stretched during the winding so that the diameter is reduced from .0056 to .0055, an amount too small to detect with a micrometer, there will be an increase in resistance of 6½ per cent.

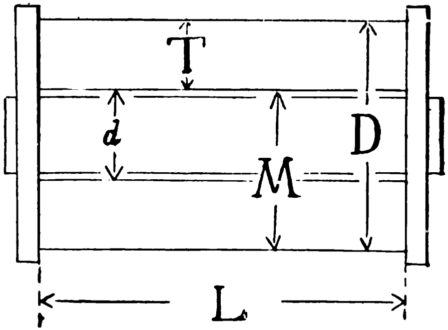
A slight variation in the thickness of the insulation will also make a marked change in the amount of wire in a winding.

In a given bobbin if a wire .005" in diameter insulated to .007" in diameter had a resistance of 2212 ohms, this same wire, insulated to .0065 in diameter, would have a resistance of 2565 ohms, an increase of 16 per cent.

It then becomes important to know the weight of the insulated wire in the finished magnet; the weight of the silk compared with the weight of the copper is often assumed to be too small to consider, and here appears another error of 11½ per cent. assuming that the .0056" bare wire is insulated to .0081 or to a 2½ mil increase.

It is the purpose of the author to call the student's particular attention to apparently negligible factors and show clearly how materially they affect the results.

Actual Calculations.



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Let D = true diameter of winding in inches,

d = diameter of core + sleeve " "

L = length of winding in inches.

M = average diameter of winding space or average diameter of one turn in inches.

T = thickness of winding space in inches.

n = number of layers.

N = number of turns.

Δ = diameter of wire in inches.

i = increase in diameter in inches due to insulation.

g = diameter of wire + insulation in inches.

Λ = length of wire in inches.

ρ = resistance of winding in ohms.

E = volts.

I = current in amperes.

W = watts.

h = constant for cotton covered wires = .1547.

Ω = ohms per pound for bare wires.

b = constant for silk covered wires = .1161.

a = % of copper in insulated wire.

A = weight of cotton in any size of cotton covered copper wire.

ω = ohms per inch for bare wires.

B = weight of silk in any size of silk covered copper wire.

θ = ohms per pound for insulated wires.

Δ^2 = cross section of wire in circular inches.

Σ = cross section of the insulation in circular inches.

λ = weight of insulated wire in pounds.

c = constant = .00000271056.

$$K = \frac{c}{\Delta^2} = \pi\,\omega$$

$$R = \frac{K}{g^2}$$

$$W = \frac{R}{\theta}$$

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Referring to the sketch above it is evident that the amount of wire that will be contained in the magnet is proportional to M L T, which is equal to $\frac{D^2 - d^2}{4} L$. It is found convenient to use both of these expressions. The length of wire Λ that can be coiled on a bobbin $= \frac{\pi M L T}{g^2}$

The resistance of the wire $\rho = \frac{\pi \times \text{ohms per inch} \times M L T}{g^2}$

If we assign to the letter K the value represented by $\pi \times$ohms per inch and assign to g the values as furnished by the manufacturers, we can put $R = \frac{K}{g^2}$ and with a prepared table giving the R values for all sizes of wire insulated with either cotton or silk the formula for resistance becomes simply $\rho = R M L T$.

The resistance of a copper wire for any length, multiplied by the area of its cross section, is equal to the resistance of any other copper wire of the same length multiplied by the area of its cross section.

The factor W bears the same relation to the weight of wire that the factor R bears to the resistance of the wire, and represents the weight of insulated wire which will be contained in a winding space having an M L T of unity.

Therefore $\gamma = W M L T$

$$n = \frac{T}{g}$$

$$M = \frac{D + d}{2}$$

$$T = \frac{D - d}{2} \qquad M T = \frac{D^2 - d^2}{4}$$

$$i = g - \Delta$$

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Working Formulas.

$$N = \frac{T\ L}{g^2} = \frac{(D - d)\ L}{2\ g^2}$$

$$\Delta = g - i$$

$$I = \frac{W}{E} = \frac{E}{\rho} = \sqrt{\frac{W}{\rho}}$$

$$\rho = \frac{E^2}{W} = \frac{E}{I} = \frac{W}{I^2}$$

$$W = E\ I = I^2\ \rho = \frac{E^2}{\rho}$$

$$E = \frac{W}{I} = I\ \rho = \sqrt{\rho\ W}$$

$$K = \frac{c}{\Delta^2} = \pi\ \omega = R\ g^2 = W\ \theta\ g^2 = W\ a\ \Omega\ g^2$$

$$R = \frac{K}{g^2} = \frac{c}{\Delta^2\ g^2} = \frac{\pi\ \omega}{g^2} = W\ \theta$$

$$\theta = \frac{R}{W} = \frac{K}{g^2\ W} = \frac{c}{W\ \Delta^2\ g^2} = \frac{\pi\ \omega}{W\ g^2} = a\ \Omega$$

$$W = \frac{R}{\theta} = \frac{c}{\theta\ \Delta^2\ g^2} = \frac{K}{\theta\ g^2} = \frac{\pi\ \omega}{\theta\ g^2}$$

$$\omega = \frac{K}{\pi} = \frac{c}{\Delta^2\ \pi} = \frac{R\ g^2}{\pi} = \frac{W\ \theta\ g^2}{\pi}$$

$$g = \sqrt{\frac{K}{R}} = \sqrt{\frac{\pi\ \omega}{R}} = \sqrt{\frac{c}{\Delta^2\ R}} = \sqrt{\frac{K}{W\ \theta}} = \Delta + i.$$

$$c = K\ \Delta^2 = \pi\ \omega\ \Delta^2 = R\ g^2\ \Delta^2 = W\ \theta\ g^2\ \Delta^2$$

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$$\Omega = \frac{\theta}{a} = \frac{R}{a\,W} = \frac{K}{a\,W\,g^2} = \frac{c}{a\,W\,\Delta^2\,g^2} = \frac{\pi\,\omega}{W\,g^2\,a}$$

$$a = \frac{\theta}{\Omega} = \frac{R}{\Omega\,W} = \frac{\pi\,\omega}{\Omega\,W\,g^2}$$

$$\Delta^2 = \frac{c}{K} = \frac{c}{R\,g^2} = \frac{c}{\pi\,\omega} = \frac{c}{W\,\theta\,g^2}$$

From the data given the following values are obtained :

$$\rho = R\,M\,L\,T = \frac{R\,L\,(D^2 - d^2)}{4} = \frac{E^2}{\pi\,D\,L}$$

$$i = \sqrt{\frac{c}{K\,\Delta^2}} - \Delta$$

$$R = \frac{4\,\rho}{L(D^2 - d^2)} = \frac{4\,E}{I\,L(D^2 - d^2)} = \frac{4\,E^2}{\pi D\,L^2\,(D^2 - d^2)}$$

$$E = \sqrt{L\,\pi\,D\,\rho} = \frac{I\,R\,L\,(D^2 - d^2)}{4} = \frac{I\,N\,K\,(D + d)}{2} = \sqrt{\frac{\pi\,R\,D\,L^2\,(D^2 - d^2)}{4}}$$

$$L = \sqrt{\frac{4\,E^2}{\pi\,D\,R(D^2 - d^2)}} = \frac{E^2}{\pi\,D\,\rho} = \frac{2\,N\,g^2}{(D - d)} = \frac{4\,\rho}{R\,(D^2 - d^2)} = \frac{4\,E}{R\,L\,(D^2 - d^2)}$$

$$D = \frac{E^2}{\pi\,\rho\,L} = \sqrt{\frac{4\,\rho}{R\,L} + d^2} = \sqrt{\frac{4\,E}{I\,R\,L} + d^2} = \frac{2\,N\,g^2}{L} + d = \frac{2\,E}{I\,N\,K} - d.$$

$$d = \sqrt{D^2 - \frac{4\,E^2}{\pi D R L}} = \sqrt{D^2 - \frac{4\,E}{I\,R\,L}} = \sqrt{D^2 - \frac{4\,\rho}{R\,L}} = D - \frac{2\,g^2\,N}{L} = \frac{2\,E}{I\,N\,K} - D$$

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$$I = \frac{E}{RMLT} = \frac{4\,E}{R\,L\,(D^2 - d^2)},\quad N = \frac{T\,L}{g^2} = \frac{L\,(D-d)}{2\,g^2}$$

$$I\,N = \frac{E}{M\,K} = \frac{2\,E}{K(D+d)} = \frac{2\,E\,\Delta^2}{c(D+d)}\,.$$

$$n = \frac{T}{g} = \frac{D-d}{2\,g}$$

$$g = \sqrt{\frac{L\,(D-d)}{2\,N}}$$

$$K = \frac{2\,E}{I\,N\,(D+d)}.$$

$$\Delta = \sqrt{\left(\sqrt{\frac{c\,L\,(D^2-d^2)}{4\,\rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$$

$$\Delta = \sqrt{\left(\sqrt{\frac{c\,\pi\,D\,L^2\,(D^2-d^2)}{4\,E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$$

$$i = \sqrt{\frac{c\,L\,(D^2-d^2)}{4\,\rho\,\Delta^2}} - \Delta = \sqrt{\frac{c\,\pi\,D\,L^2\,(D^2-d^2)}{4\,E^2\,\Delta^2}} - \Delta$$

Diameter of Wire to Carry Given Current.

To find the diameter of the wire which will safely carry a continuous current we have $R = \frac{E^2}{\pi\,D\,L^2\,M\,T}$ by allowing 1 watt per square inch for radiation, no allowance being made for end flanges or core. If the winding is of great depth or closely confined another constant must be substituted for π in the formula. A fair example where π is the constant is in a winding where $D = 2.5''$ $L = 2''$ $d = 1\frac{1}{8}''$. In calculations where the size of insulated copper wire is required the value of R may first be found, then by reference to the table, in which are given the values of R for

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the various sizes of insulated wires, the size of the wire and of the insulation may be found.

In case the value of R in the problem lies between two values of R in the table, the value of R for the smaller size of wire may be taken and with it a new D may be found which will satisfy the conditions of the problem.

EXAMPLE: Let $D = 1$, $d = .43$, $L = 3$ $\rho = 125$

$$D^2 - d^2 = 1. - .185 = .815$$

From (1). $$R = \frac{4\rho}{(D^2 - d^2)L} = \frac{500}{.815 \times 3} = \frac{500}{2.445} = 204.5$$

In the table the value for R (204.5) lies between the values of R for No. 30 and No. 31 single silk covered wire. Taking the value of R for No. 31 single silk covered wire (261.6) and solving for the new D:

$$D = \sqrt{\frac{4\rho}{RL} + d^2} = \sqrt{\frac{500}{261.6 \times 3} + .185}$$

$$= \sqrt{.638 + .185} = \sqrt{.823} = .907$$

From the above it is evident that it is very important to know the *exact* value of R.

Tables giving values of K for all sizes of wire and values for R for all sizes of wire and insulation, both cotton and silk, are printed on page 76.

A rod of soft drawn commercial copper 1" in diameter (1 circular inch in cross section) and one foot in length, has a resistance @ 68° F, of .00010353568 international ohms.

Then a wire .001 in. in diameter (.000001 circular in. in cross section) and one foot in length, under the same conditions, has a resistance of 10.353568 ohms, or in other words:—

A commercial copper wire one circular mil in cross section has a resistance @ 68° F. of 10.353568 ohms per foot.

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Since $K = \pi\,\omega$ and also $\frac{c}{\Delta^2}$

$$c = \pi\,\omega\ \Delta^2 = \frac{3.1416 \times 10.353568 \times .000001}{12}$$

$$= \frac{.00003252677}{12} = .00000271056$$

Therefore to find the value of K for any size of wire, divide the constant c by the cross section of the wire in circular mils.

Likewise with the factor R which is equal to $\frac{K}{g^2}$, in case the insulation thickness is different from that given in the table, a new R may be easily determined.

Diameter of Wire to have Given Resistance.

To find the exact diameter of a copper wire which will satisfy the conditions for a given bobbin when the resistance required is also given and the insulation previously determined on, proceed as follows:

Since $g^2 = \frac{c}{\Delta^2\,R}$

$$g^2\,\Delta^2 = \frac{c}{R}$$

$$g\,\Delta = \sqrt{\frac{c}{R}}$$

Since $g = \Delta + i$

$$\Delta^2 + \Delta\,i = \sqrt{\frac{c}{R}}$$

Completing the square:—

$$\Delta^2 + \Delta i + \frac{i^2}{4} = \sqrt{\frac{c}{R}} + \frac{i^2}{4}$$

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$$\Delta + \frac{i}{2} = \sqrt{\sqrt{\frac{c}{R}} + \frac{i^2}{4}}$$

$$\Delta = \sqrt{\left(\sqrt{\frac{c}{R}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

Substituting $\frac{\rho}{M L T}$ for R we have

$$\Delta = \sqrt{\sqrt{\frac{c}{\frac{\rho}{M L T}}} + \frac{i^2}{4}} - \frac{i}{2}$$

$$= \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

Thickness of Insulation in a Given Coil.

To find the thickness of insulation necessary to insulate a given wire, to satisfy the conditions of the bobbin and resistance.

$$\Delta^2 + \Delta i = \sqrt{\frac{c}{R}}$$

$$i = \frac{\sqrt{\frac{C}{R}} - \Delta^2}{\Delta}$$

$$= \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$$

A serious error made in computing tables for insulated wires is the allowance of 90% of the gross weight for the wire and 10% for the insulation.

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The table on page 78 shows the fallacy of this method. The table is computed on the following principle:

The specific gravity of copper is to that of cotton as 86.6 : 13.4

The specific gravity of copper is to that of silk as 89.6 : 10.4

If then a copper wire having an end area Δ^2 be insulated with Σ cotton, 86.6 Δ^2 is the relative weight of copper, and 13.4Σ is the relative weight of cotton in the insulated wire.

Therefore, $$\frac{86.6\ \Delta^2}{86.6\ \Delta^2 + 13.4\ \Sigma} = \%\text{ of copper.} \qquad (1)$$

Likewise with a copper wire insulated with silk:

$$\frac{89.6\ \Delta^2}{89.6\ \Delta^2 + 10.4\ \Sigma} = \%\text{ of copper.} \qquad (2)$$

Multiplying the weight of the insulated wire by the per cent. of copper the weight of the copper is obtained, and by subtracting the weight of the copper from the weight of the insulated wire, the weight of the cotton is obtained; or the weight of the cotton can be found after the manner of finding the weight of copper. The same operation is repeated for finding the weights of copper and silk. Since a = per cent. of copper in either case formulae (1) must always be used for cotton insulated wire and (2) for silk insulated wire.

Weight of Copper in a Given Coil.

Given the gross weight of a coil of No. 25 silk insulated wire, the diameter of which including wire and insulation = g and the diameter of the copper Δ, to find the weight of copper.

$$g^2 - \Delta^2 = \Sigma$$

Let $g = .03396,$

$\Delta = .03196,$

Then $\Delta^2 = .001022$

$$\Sigma = g^2 - \Delta^2 = .001152 - .001022 = .00013$$

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Substituting values of Δ^2 and Σ in (2)

$$a = \frac{89.6 \times .001022}{(89.6 \times .001022) + (10.4 \times .00013)} = \frac{.091571}{.091571 + .0001352}$$

$$= .985 \text{ or } 98.5 \text{ per cent.}$$

Having found the relative weights of copper and cotton, and copper and silk, a new table giving "Ohms per Pound" is shown on page 77 computed from this principle.

It is very evident that unless the exact ohms per pound of a given wire is known, the error will be very great. A comparison between the table on page 77 and other tables will show the discrepancy in the latter.

Referring to the table on page 77 which gives the Ohms per pound for all sizes of bare copper wire, any size wire may be selected and by reversing the operation the Ohms per pound for any style of insulated wire may be found.

Thus, in the last example:—

In the table the wire .03196 inches in diameter has 3.278 ohms per pound and the ohms per pound of the wire with .002 inches insulation will be only 98.5% of the ohms per pound of the bare wire.

Thus:, $3.278 \times .985 = 3.23,$

which is the value given in the table on page 77.

The weight of cotton in any size of cotton covered copper wire is equal to,

$$\frac{\Sigma}{\Delta^2} \times \frac{13.4}{86.6} = \frac{\Sigma}{\Delta^2} \times .1547,$$

or for silk

$$\frac{\Sigma}{\Delta^2} \times \frac{10.4}{89.6} = \frac{\Sigma}{\Delta^2} \times .1161.$$

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Therefore to find the weight in pounds of insulation that will insulate a given bare copper wire to any thickness, divide the continued product of the area of the cross section of the insulation in circular inches, the constant for that style of insulation, and the weight of the given wire in pounds by the cross sectional area of the copper in circular inches.

Thus: For silk, $B = \frac{\Sigma\ b\ \lambda}{\Delta^2}$

For cotton, $A = \frac{\Sigma\ h\ \lambda}{\Delta^2}$.

EXAMPLE: Given the weight and size of a bare copper wire, to find the weight of cotton required to insulate it to .004 in. increase:

Let $\Delta = .0403$ (No. 18 B & S)

$$\lambda = 980$$

Then $$g = \Delta + i = .0403 + .004 = .0443$$

$$A = \frac{\Sigma\ h\ \lambda}{\Delta^2} = \frac{h\ \lambda\ (g^2 - \Delta^2)}{\Delta^2} = \frac{151.6 \times .0003384}{.00162409} = \frac{.05130144}{.00162409}$$

$$= 31.58.$$

Transforming above rule:

FOR SILK.	FOR COTTON.
$B = \frac{\Sigma\ b\ \lambda}{\Delta^2}$	$A = \frac{\Sigma\ h\ \lambda}{\Delta^2}$
$\Delta^2 = \frac{\Sigma\ b\ \lambda}{B}$	$\Delta^2 = \frac{\Sigma\ h\ \lambda}{A}$
$\Sigma = \frac{B\ \Delta^2}{b\ \lambda}$	$\Sigma = \frac{\Delta^2\ A}{h\ \lambda}$
$b = \frac{B\ \Delta^2}{\Sigma\ \lambda}$	$h = \frac{\Delta^2\ A}{\Sigma\ \lambda}$
$\lambda = \frac{B\ \Delta^2}{\Sigma\ b}$	$\lambda = \frac{\Delta^2\ A}{\Sigma\ \lambda}$

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THE VALUES SHOWN IN COLUMNS "R" AND "W" OF THIS TABLE REPRESENT RESPECTIVELY THE RESISTANCES AT 68° F., AND THE WEIGHT IN POUNDS, OF COTTON AND SILK INSULATED WIRE WINDINGS WHEN MLT = 1.

Size of Wire B&S	Diam. in inches Δ	Circ. inches Δ²	K	COTTON. Insulation t	s in inches	s^2 Circ. inches	R	Ohms per pound θ	W	SILK. Insulation t	s in inches	s^2 Circ. inches	R	Ohms per pound θ	W
10	.1019	.01038	.000261	.008	.1099	.0121	.02155	.0308	.7						
11	.09074	.008234	.000329	.008	.09874	.00975	.03375	.049	.689						
12	.08081	.006530	.000415	.008	.08881	.00788	.0527	.0777	.675						
13	.07196	.005178	.000523	.008	.07996	.0064	.0818	.123	.665						
14	.06408	.004107	.00066	.008	.07208	.0052	.127	.195	.651						
15	.05707	.003257	.000833	.008	.06507	.00423	.1965	.3065	.638						
16	.05082	.002583	.001049	.008	.05882	.00346	.303	.488	.621						
17	.04526	.002048	.001323	.008	.05326	.002835	.467	.768	.608						
18	.04030	.001624	.001668	.008	.04830	.002335	.713	1.218	.588						
19	.03589	.001288	.002103	.008	.04389	.001925	1.0925	1.915	.570						
20	.03196	.001022	.00265	.004	.03596	.001293	2.05	3.15	.65	.0025	.03446	.001185	2.235	3.22	.695
21	.02846	.000810	.00335	.004	.03246	.001053	3.18	4.97	.64	.0025	.03096	.000958	3.49	5.1	.685
22	.02535	.0006424	.00422	.004	.02935	.000862	4.895	7.87	.622	.0025	.02785	.000776	5.43	8.08	.672
23	.02257	.0005095	.00532	.004	.02657	.000705	7.55	12.45	.606	.0025	.02507	.000628	8.48	12.8	.662
24	.0201	.000404	.00671	.004	.0241	.000580	11.56	19.65	.59	.0025	.0226	.000511	13.1	20.35	.645
25	.0179	.0003204	.00846	.004	.0219	.000479	17.66	30.9	.572	.0025	.0204	.000416	20.3	32.2	.631
26	.01594	.0002541	.01065	.004	.01994	.000397	26.86	48.5	.554	.0025	.01844	.000340	31.4	50.9	.617
27	.0142	.0002015	.01345	.004	.0182	.000332	40.5	76.5	.530	.0025	.0167	.000279	48.2	80.8	.597
28	.01264	.0001598	.01696	.004	.01664	.000277	61.3	120.	.510	.0025	.015145	.000229	74.	127.5	.581
29	.01126	.0001267	.0214	.004	.01526	.000233	91.8	190.5	.482	.0025	.01376	.0001895	112.8	201.5	.56
30	.01003	.0001005	.02695	.004	.01403	.000197	136.8	294.5	.464	.0025	.01253	.000157	171.6	318.	.539
31	.008928	.0000797	.034	.004	.012928	.000167	203.5	461.	.441	.0025	.011428	.0001305	260.5	502.	.518
32	.00795	.00006321	.0429	.004	.01195	.000143	299.8	717.	.418	.0025	.01045	.000109	393.	790.	.498
33	.00708	.00005013	.0541	.004	.01108	.000123	439.5	1115.	.394	.0025	.00958	.0000918	589.	1138.	.517
34	.006305	.00003975	.0682	.004	.010305	.000106	643.	1715.	.375	.0025	.008805	.0000775	880.	1940.	.453
35	.005615	.00003152	.086	.004	.009615	.0000925	930.	2640.	.352	.0025	.008115	.0000658	1307.	3040.	.43
36	.005	.000025	.10845	.004	.009	.0000810	1340.	4070.	.329	.0025	.0075	.0000562	1930.	4720.	.409
37	.004453	.00001983	.1365	.004	.008458	.0000714	1912.	6180.	.309	.0015	.005953	.0000354	3860.	7970.	.484
38	.003965	.00001572	.1725	.004	.007965	.0000635	2715.	9430.	.288	.0015	.005465	.0000299	5770.	12550.	.459
39	.003531	.00001247	.217	.004	.007581	.0000567	3833.	14200.	.27	.0015	.005081	.0000253	8590.	19600.	.438
40	.003145	.000009888	.2741	.004	.007145	.0000511	5360.	21300.	.252	.0015	.004645	.0000216	12690.	30800.	.412

OHMS PER POUND OF INSULATED WIRE COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B & S)	Diam. of Wire, bare	Diam. Insulated with Silk	Diam. Insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

Size of Wire B & S Gauge	Diam. in Inches	Bare @ 68° F	OHMS, PER POUND — SILK — SINGLE — 1½ mil increase	SILK — SINGLE — 2 mil increase	SILK — SINGLE — 3 mil increase	SILK — DOUBLE — 4 mil increase	COTTON — SINGLE — 4 mil increase	COTTON — DOUBLE — 8 mil increase
20	.03196	3.278	3.245	3.23	3.21	3.175	3.15	3.02
21	.02846	5.212	5.150	5.125	5.08	5.025	4.97	4.72
22	.02535	8.287	8.17	8.12	8.05	7.96	7.87	7.44
23	.02257	13.18	12.95	12.90	12.78	12.65	12.45	11.7
24	.02010	20.95	20.55	20.45	20.20	19.95	19.65	18.25
25	.01790	33.32	32.65	32.4	31.9	31.5	30.9	28.45
26	.01594	52.97	51.8	51.3	50.5	49.7	48.5	44.3
27	.0142	84.23	82.2	81.4	79.8	78.3	76.5	68.8
28	.01264	133.9	130.	129.	126.	123.5	120.	106.5
29	.01126	213.	206.5	204.	199.	194.	190.5	164.
30	.01003	338.6	326	322.	313.	306.5	294.5	252.
31	.008928	538.4	516.0	510.	493.	477.	461.	384.5
32	.00795	856.2	817.	803.	775.	747.	717.	585.
33	.00708	1361.	1290.	1265.	1215.	1165.	1115.	880.
34	.006305	2165.	2020.	1995.	1900.	1810.	1715.	1315.
35	.005615	3441.	3210.	3140.	2980.	2820.	2640.	1960.
36	.005	5473.	5070.	4880.	4630.	4340.	4070.	2890.
37	.004453	8702.	7970.	7680.	7180.	6660.	6180.	4230.
38	.003965	13870.	12550.	12100.	11150.	10250.	9430.	6150.
39	003531	22000.	19600.	18850.	17000.	15600.	14200.	8850.
40	.003145	34980.	30800.	29300.	26400.	23650.	21300.	12500.

COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B & S)	Diameter of Wire (bare)	Diameter insulated with Silk	Diameter insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

JERSEY CITY, July, 1900. R. VARLEY.

WEIGHT OF COPPER IN 100 LBS. OF INSULATED WIRE.

Size of Wire B & S Gauge	SILK				COTTON	
	SINGLE			DOUBLE	SINGLE	DOUBLE
	1½ mil increase	2 mil increase	3 mil increase	4 mil increase	4 mil increase	8 mil increase
20	99.	98.5	97.8	97.	96.2	92.2
21	98.8	98.3	97.5	96.5	95.5	90.8
22	98.6	98.	97.2	96.2	95.	89.8
23	98.4	97.8	96.8	95.8	94.3	88.6
24	98.2	97.7	96.3	95.2	93.7	87.
25	98.	97.2	95.8	94.6	92.8	85.5
26	97.8	97.	95.3	93.8	91.8	83.8
27	97.5	96.7	94.8	93.	90.8	81.7
28	97.2	96.2	94.2	92.2	89.7	79.5
29	96.8	95.7	93.4	91.2	88.5	77.
30	96.3	95.2	92.6	90.6	87.	74.5
31	95.8	94.6	91.7	88.6	85.5	71.8
32	95.4	93.8	90.5	87.3	83.7	68.3
33	94.8	93.	89.25	85.7	81.8	64.7
34	94.2	92.2	87.8	83.7	79.4	61
35	93.4	91.2	86.7	82.2	76.8	57.
36	92.6	89.25	84.7	79.3	74.3	52.8
37	91.6	88.4	82.6	76.7	71.2	48.7
38	90.5	87.2	80.4	73.8	68.	44.4
39	89.2	85.7	77.2	70.8	64.6	40.2
40	88.1	83.8	75.5	67.7	60.8	35.8

COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B & S)	Diameter of Wire (bare)	Diameter insulated with Silk	Diameter insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

JERSEY CITY, July, 1900. R. VARLEY.

Standard Copper Wire Table.

(Copied from the "Supplement to Transactions of American Institute of Electrical Engineers," October, 1893.)

Giving Weights, Lengths, and Resistances of Wires @ 20° C. or 68° F., of Matthiessen's Standard Conductivity, for A. W. G. (Brown & Sharpe).

A. W. G.	DIAMETER	AREA.	WEIGHT.		LENGTH.		RESISTANCE.	
B. & S.	Inches.	Circ'l'r Mils.	Lbs. Per Foot.	Lbs. Per Ohm.	Feet Per Lb.	Feet Per Ohm.	Ohms Per Lb.	Ohms Per Foot.
			.0000030274 x C. M.	.00000006184 x C. M.²	330330 / C. M.	.096585 x C. M.	3420000 / C. M.²	10.353560 / C. M.
0000	0.460	211,600.	0.6405	13,090.	1.561	20,440.	0 00007639	0.00004893
000	0.4096	167,800.	0.5080	8,232.	1.969	16,210.	0.0001215	0 00006170
00	0.3648	133,100.	0.4028	5,177.	2.482	12,850.	0.0001931	0 00007780
0	0.3249	105,500.	0.3195	3,256.	3.130	10,190.	0.0003071	0 00009811
1	0.2893	83,690.	0.2533	2,048.	3.947	8,083.	0.0004883	0.0001237
2	0.2576	66,370.	0.2009	1,288.	4.977	6,410.	0.0007765	0.0001560
3	0.2294	52,630.	0.1593	810.0	6.276	5,084.	0.001235	0.0001967
4	0.2043	41,740.	0.1264	509.4	7.914	4,031.	0.001963	0.0002480
5	0.1819	33,100.	0.1002	320.4	9.980	3,197.	0.003122	0.0003128
6	0.1620	26,250.	0.07946	201.5	12.58	2,535.	0.004963	0.0003944
7	0.1443	20,820.	0.06302	126.7	15.87	2,011.	0.007892	0.0004973
8	0.1285	16,510.	0.04998	79.69	20.01	1,595.	0.01255	0.0006271
9	0.1144	13,090.	0.03963	50.12	25.23	1,265.	0.01995	0.0007908
10	0.1019	10,380.	0.03143	31.52	31.82	1,003.	0.03173	0.0009972
11	0.09074	8,234.	0.02493	19.82	40.12	795.3	0.05045	0.001257
12	0.08081	6,530.	0.01977	12.47	50.59	630.7	0.08022	0.001586
13	0.07196	5,178.	0.01568	7.840	63.79	500.1	0.1276	0.001999
14	0.06408	4,107.	0.01243	4.931	80.44	396.6	0.2028	0.002521
15	0.05707	3,257.	0.009858	3.101	101.4	314.5	0.3225	0.003179
16	0.05082	2,583.	0.007818	1.950	127.9	249.4	0.5128	0.004009
17	0.04526	2,048.	0.006200	1.226	161.3	197.8	0.8153	0.005055
18	0.04030	1,624.	0.004917	0.7713	203.4	156.9	1.296	0.006374
19	0.03589	1,288.	0.003899	0.4851	256.5	124.4	2.061	0.008038
20	0.03196	1,022.	0.003092	0.3051	323.4	98.66	3.278	0.01014
21	0.02846	810.1	0.002452	0.1919	407.8	78.24	5.212	0.01278
22	0.02535	642.4	0.001945	0.1207	514.2	32.05	8.287	0.01612
23	0.02257	509.5	0.001542	0.07589	648.4	49.21	13.18	0.02032
24	0.02010	404.0	0.001223	0.04773	817.6	39.02	20.95	0.02563
25	0.01790	320.4	0.0009699	0.03002	1,031.	30.95	33.32	0.03231
26	0.01594	254.1	0.0007692	0.01888	1,300.	24.54	52.97	0.04075
27	0.0142	201.5	0.0006100	0.01187	1,639.	19.46	84.23	0.05138
28	0.01264	159.8	0.0004837	0.007466	2,067.	15.43	133.9	0.06479
29	0.01126	126.7	0.0003836	0.004696	2,607.	12.24	213.0	0.08170
30	0 01003	100.5	0.0003042	0.002953	3,287.	9.707	338.6	0.1030
31	0 008928	79.70	0.0002413	0.001857	4,145.	7.698	538.4	0.1299
32	0 007950	63.21	0.0001913	0.001168	5,227.	6.105	856.2	0.1638
33	0 007080	50.13	0.0001517	0.0007346	6,591.	4.841	1,361.	0.2066
34	0 003305	39.75	0.0001203	0.0004620	8,311.	3.839	2,165.	0.2605
35	0 005615	31.52	0 00009543	0.0002905	10,480.	3.045	3,441.	0.3284
36	0.0050	25.0	0 00007568	0.0001827	13,210.	2.414	5,473.	0.4142
37	0 004453	19.83	0 00006001	0.0001149	16,660.	1.915	8,702.	0.5222
38	0 003965	15.72	0 00004759	0 00007210	21,010.	1.519	13,870.	0.6585
39	0 003531	12.47	0 00003774	0 00004545	26,500.	1.204	22,000.	0.8304
40	0 003145	9.888	0 00002993	0 00002858	33,410.	0.9550	34,980.	1.047

[For Explanatory Remarks on this Table, see opposite page.]

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EXPLANATION OF TABLE.

The data from which this table has been computed are as follows:—Matthiessen's standard resistivity, Matthiessen's temperature coefficients, specific gravity of copper = 8.89. Resistance in terms of the international ohm.

Matthiesson's standard 1 metre-gramme of hard drawn copper = 0.1469 B. A. U. @ 0° C. Ratio of resistivity hard to soft copper 1.0226.

Matthiesson's standard 1 metre-gramme of soft drawn copper = 0.14365 B. A. U. @ 0° C. One B. A. U. = 0.9866 international ohms.

Matthiesson's standard 1 metre-gramme soft drawn copper = 0.141729 international ohm @ 0° C.

Temperature coefficients of resistance for 20° C., 50° C., and 80° C., 1.07968, 1.20625, and 1.33681 respectively. 1 foot = 0.3048028 metre, 1 pound = 453.59256 grammes.

Although the entries in the table are carried to the fourth significant digit, the computations have been carried to at least five figures. The last digit is therefore correct to within half a unit, representing an arithmetical degree of accuracy of at least one part in two thousand. The diameters of the B. & S. or A. W. G. wires are obtained from the geometrical series in which No. 0000 = 0.4600 inch and No. 36 = 0.005 inch, the nearest fourth significant digit being retained in the areas and diameters so deduced.

It is to be observed that while Matthiesson's standard of resistivity may be permanently recognized, the temperature coefficient of its variation which he introduced, and which is here used may in future undergo slight revision.

F. B. CROCKER, W. E. GEYER,
G. A. HAMILTON, A. E. KENNELLY, Chairman,
Committee on "Units and Standards."

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R\,L\,(D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L\,(D - d)}{2\,g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4\,\rho}{R\,L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4\,\rho}{L\,(D^2 - d^2)}$	"	89
5.	" Core, ~~Insulated~~ Wire, Diameter and Resistance, find Length	$L = \frac{4\,\rho}{R\,(D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4\,E^2}{\pi\,D\,L^2\,(D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi\,D\,L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4\,E}{R\,L\,(D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I\,N = \frac{2\,E}{K\,(D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi\,R\,D\,L^2\,(D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho\,\Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2\,\Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L\,(D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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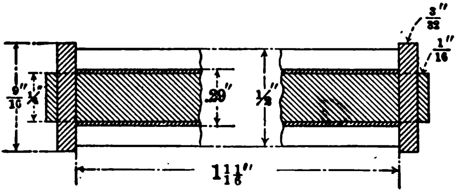
EXAMPLE No. 1.



Wire No. 30 S. S. C.

$$\rho = \frac{171.6 \times 1.6875 \times (.5^2 - .29^2)}{4}$$

$= 12 +$ Ohms. (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R\,L\,(D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L\,(D - d)}{2\,g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4\,\rho}{R\,L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4\,\rho}{L\,(D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4\,\rho}{R\,(D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4\,E^2}{\pi\,D\,L^2\,(D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi\,D\,L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4\,E}{R\,L\,(D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I\,N = \frac{2\,E}{K\,(D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi\,R\,D\,L^2\,(D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho\,\Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2\,\Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L\,(D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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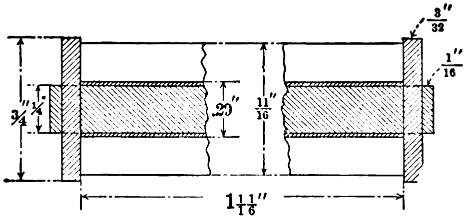
EXAMPLE No. 2.



Wire No. 35 S. S. C.

$$N = \frac{1.6875\,(.6875 - .29)}{2 \times .0000658)}$$

= 5100 Turns. (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page 83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	" 85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	" 87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	" 89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	" 91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	" 93
7.	" Diameter. Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	" 95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	" 97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{K (D + d)}$	" 99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	" 101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	" 107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	" 109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	" 115

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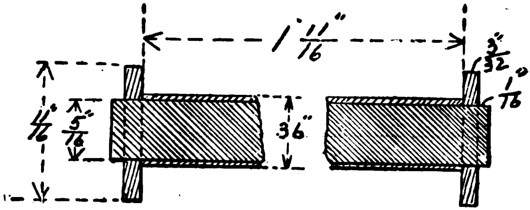
EXAMPLE No. 3.



Resistance 43 Ohms.

Wire No. 32 S. S. C.

$$D = \sqrt{\frac{4 \times 43}{393 \times 1.6875} + .36^2}$$

$= .62'' +$ (Answer).

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EXAMPLE 1. Given Bobbin and Wire, find Resistance	$\rho = \frac{R\,L\,(D^2 - d^2)}{4}$	See page	83
2. " Bobbin and Wire, find Turns	$N = \frac{L\,(D - d)}{2\,g^2}$	"	85
3. " Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4\,\rho}{R\,L} + d^2}$	"	87
4. " Bobbin and Resistance, find Wire	$R = \frac{4\,\rho}{L\,(D^2 - d^2)}$	"	89
5. " Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4\,\rho}{R\,(D^2 - d^2)}$	"	91
6. " Bobbin and Voltage, find Wire	$R = \frac{4\,E^2}{\pi\,D\,L^2\,(D^2 - d^2)}$	"	93
7. " Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi\,D\,L}$	"	95
8. " Bobbin, Voltage and Wire, find Current	$I = \frac{4\,E}{R\,L\,(D^2 - d^2)}$	"	97
9. " Core, Diameter Voltage and Wire, find Ampere Turns	$I\,N = \frac{2\,E}{K\,(D + d)}$	"	99
10. " Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi\,R\,D\,L^2\,(D^2 - d^2)}{4}}$	"	101
11. " Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	103
12. " Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	105
13. " Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho\,\Delta^2}} - \Delta$	"	107
14. " Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2\,\Delta^2}} - \Delta$	"	109
15. " D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	111
16. " D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	113
17. " D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L\,(D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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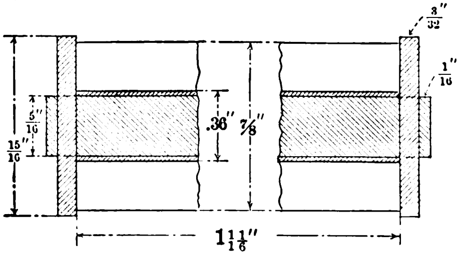
EXAMPLE No. 4.



Resistance 7.2 Ohms.

$$R = \frac{4 \times 7.2}{1.6875 \times (.875^2 - .36^2)}$$

$= 26.8 + = R =$ (Answer).

In Table, R is found opposite

No. 26 S. C. C. Wire.

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EXAMPLE 1.	Given Bobbin and Wire, fin l Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page 83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 \delta^2}$	" 85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	" 87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	" 89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	" 91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	" 93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	" 95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	" 97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	" 99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	" 101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	" 103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	" 105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	" 107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	" 109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	" 115

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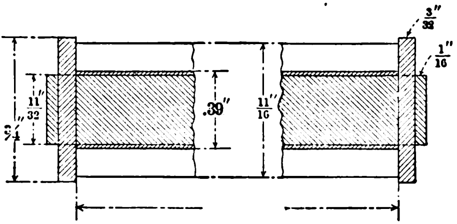
EXAMPLE No. 5.



Resistance 500 Ohms.

Wire No. 36 S. S. C.

$$L = \frac{4 \times 500}{1930\ (.6875^2 - .39^2)}$$

$= 3.2'' +$ (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R\,L\,(D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L\,(D - d)}{2\,g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4\rho}{R\,L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4\rho}{L\,(D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4\rho}{R\,(D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4\,E^2}{\pi\,D\,L^2\,(D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi\,D\,L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4\,E}{R\,L\,(D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I\,N = \frac{2\,E}{K\,(D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi\,R\,D\,L^2\,(D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,L\,(D^2 - d^2)}{4\rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,L\,(D^2 - d^2)}{4\,\rho\,\Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c\,\pi\,D\,L^2\,(D^2 - d^2)}{4\,E^2\,\Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2)\,\frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L\,(D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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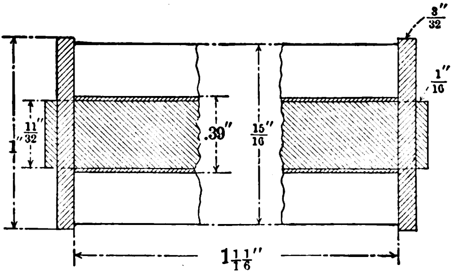
EXAMPLE No. 6.



Volts 45.

$$R = \frac{4 + 45^2}{\pi \times .9375 \times 1.875^2 \, (.9375^2 - .39^2)}$$

= 1328 R (Answer).

In Table, R is nearest to

No. 35 S. S. C.

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Example	Given	Formula	See page
EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page 83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	" 85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	" 87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	" 89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	" 91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	" 93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	" 95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	" 97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	" 99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	" 101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	" 107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	" 109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	" 115

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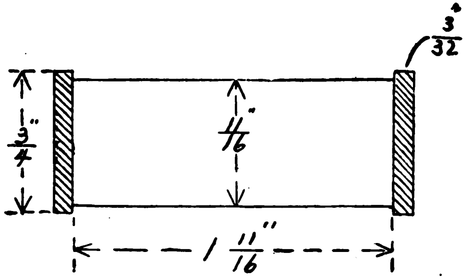
EXAMPLE No. 7.



Volts 120.

$$o = \frac{120^2}{\pi \times .6875 \times 1.6875}$$

= 3950 Ohms. (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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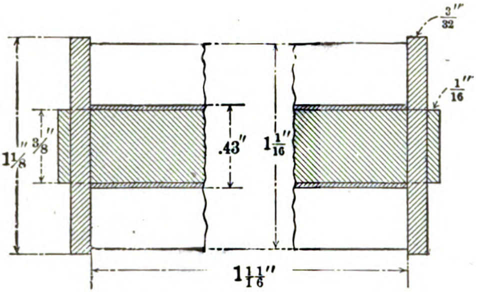
EXAMPLE No. 8.



Wire No. 27 S. S. C.

Voltage 24.

$$I = \frac{4 \times 24}{48.2 \times 1.6875\,(1.0625^2 - .43^2)}$$

$= 1.25$ Amperes. (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page 83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	" 85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	" 87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	" 89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	" 91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	" 93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	" 95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	" 97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	" 99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	" 101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	" 107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	" 109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	" 115

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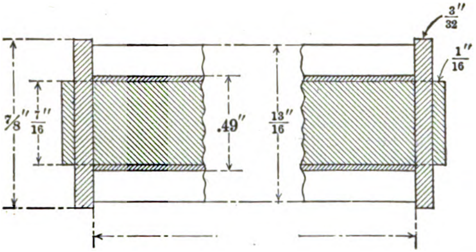
EXAMPLE No. 9.



Wire No. 24 S. C. C.

Volts 100.

$$I\,N = \frac{2 \times 100}{.00671\,(.8125 + .49)}$$

= 22883 + Ampere Turns. (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 \delta^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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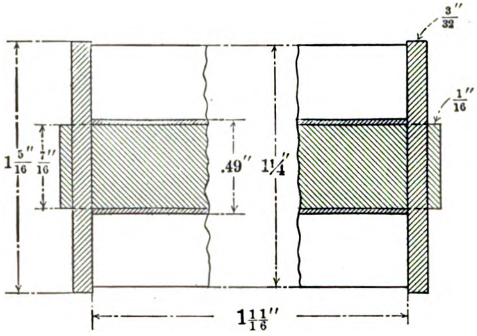
EXAMPLE No. 10.



Wire No. 24 S. S. C.

$$E = \sqrt{\frac{\pi \times 13.1 \times 1.25 \times 1.6875^2 (1.25^2 - .49^2)}{4}}$$

$= 6.9 +$ Volts. (Answer).

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Example	Given … find	Formula	See page
EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page 83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	" 85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	" 87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	" 89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	" 91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	" 93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	" 95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	" 97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	" 99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	" 101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	" 105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	" 107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	" 109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	" 113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	" 115

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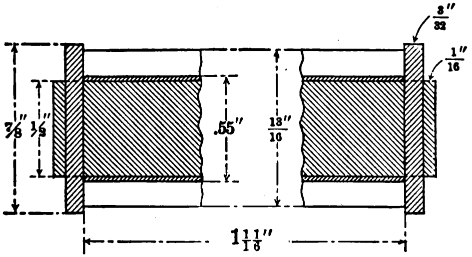
EXAMPLE No. 11.



Resistance 1.848 Ohms.

Insulation .0025″

$$\Delta = \sqrt{\left(\sqrt{\frac{.00000271 \times 1.6875\ (.8125^2 - .55^2)}{4 \times 1.848}} + \frac{.0025^2}{4}\right)} - \frac{.0025}{2}$$

= .02048″ (Answer).

= to No. 24 Wire.

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, ~~Insulated~~ Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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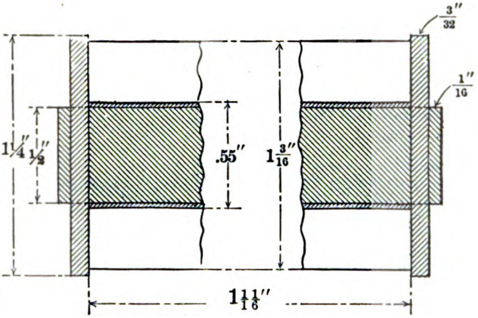
EXAMPLE No. 12.



Volts 20.

Insulation .004".

$$\Delta = \sqrt{\left(\sqrt{\frac{.0000271 \times \pi \times 1.1875 \times 1.6875^2 (1.1875^2 - .55^2)}{4 \times 20^2} + \frac{.004^2}{4}}\right) - \frac{.004}{2}}$$

= .01" (Answer).

= to No. 30 Wire.

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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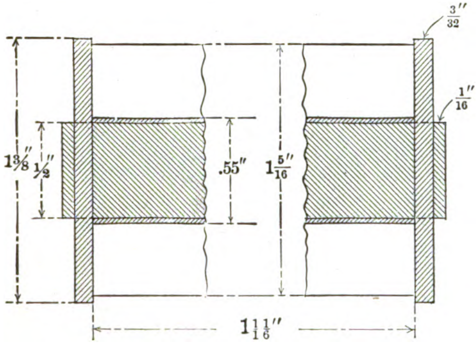
EXAMPLE 13.



Wire No. 30.

Resistance 75 Ohms.

$$i = \sqrt{\frac{.00000271 \times 1.6875\,(1.3125^2 - .55^2)}{4 \times 75 \times .01^2}} - .01$$

$= .0047''$ (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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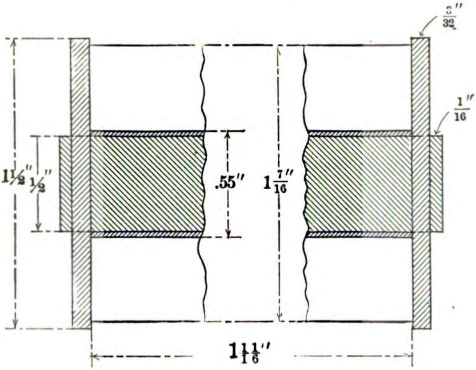
EXAMPLE No. 14.



Wire No. 22.

Volts 5.

$$i = \sqrt{\frac{.0000027\,1 \times \pi \times 1.4375 \times 1.6875^2\,(1.4375^2 - .55^2)}{4 \times 5^2 \times .02535^2}} \quad -\cdot \quad 02535$$

$$= .0056'' \quad \text{(Answer)}.$$

Example 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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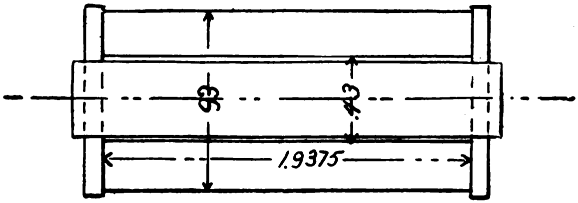
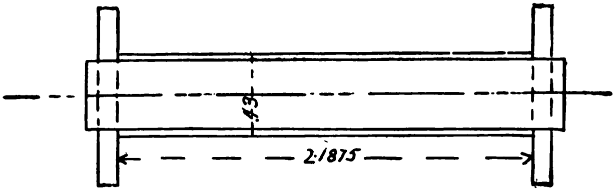
EXAMPLE No. 15.

A



B



$$D_1 = \sqrt{.43^2 + (.93^2 - .43^2)\,\frac{1.9375}{2.1875}}$$

$= .8875''$ (Answer).

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EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2} + \frac{i^2}{4}}\right) - \frac{i}{2}}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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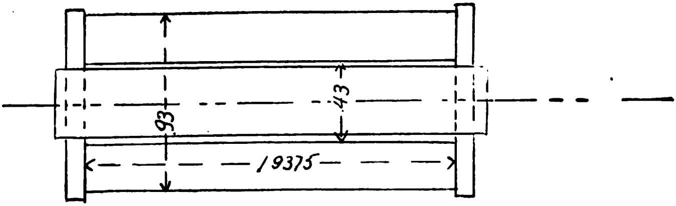
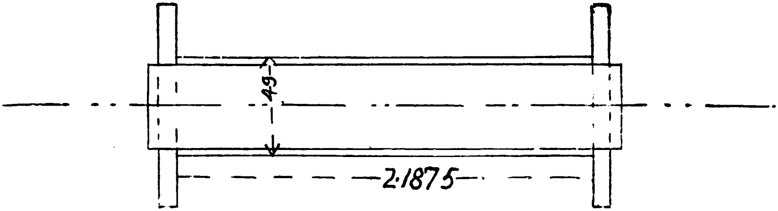
EXAMPLE No. 16.

C



E



$$D_1 = \sqrt{.49^2 + (93^2 - 43^2)\frac{1.9375}{2.1875}}$$

$$= .918'' \text{ (Answer).}$$

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Example 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$I N = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

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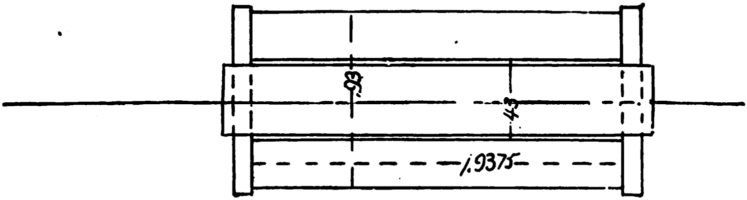
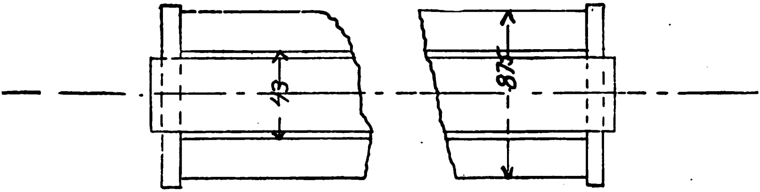
EXAMPLE No. 17.

F



G



$$L_1 = \frac{(.93^2 - .43^2)\ 1.9375}{.875^2 - .43^2}$$

$= 2.27''$ (Answer).

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The following line drawings show nearly all sizes of Telegraph and Telephone magnet bobbins. Six sizes of cores are given, also various sizes of washers. The diameter to wind to, is usually $\frac{1}{16}''$ less than the diameter of the washer. The diameter to wind on is the outside diameter of the paper sleeve which is wrapped around the core. The cuts are shown full size in all dimensions except length. The actual numerical value for length is given which would make M x L x T equal to unity in each case. The values of R and W are equal to the Resistance and Weight of the winding when that size wire opposite said values is used.

The resistance in ohms and weight in lbs. of wire contained in each bobbin will vary directly as the length between washers other things remaining constant. If it is desired to know the resistance for any winding length other than that indicated in the drawing, the desired resistance will bear the same ratio to the value R as the desired Length bears to the Length indicated in the drawing.

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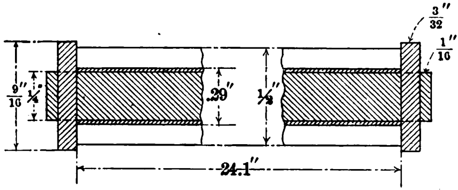

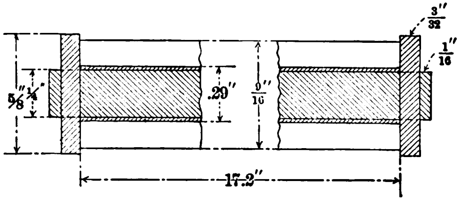

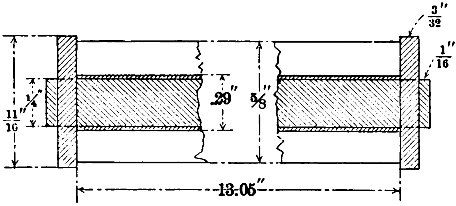

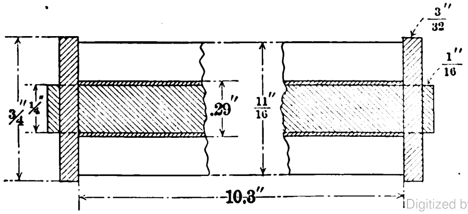

These bobbins, wound with a wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.606		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.235	.695
21	3.18	.64	3.49	.683
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.412

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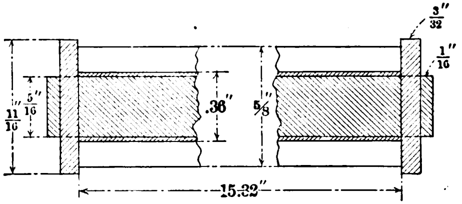

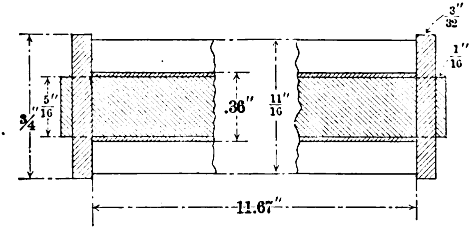

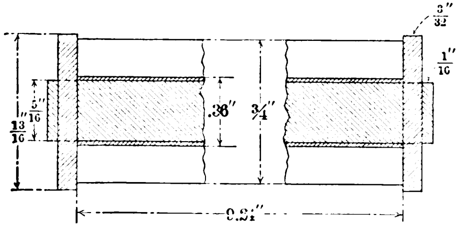

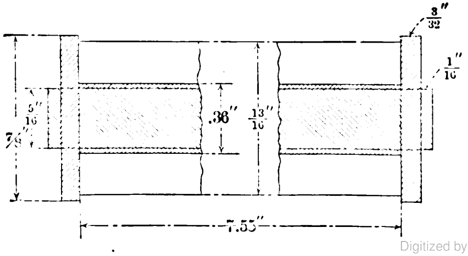

These bobbins, wound with ar wire indicated in first column, wi contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0527	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.608		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.285	.698
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.412

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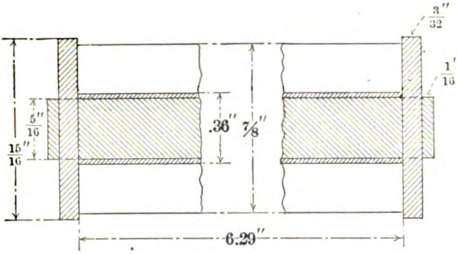

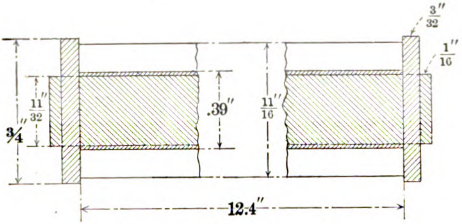

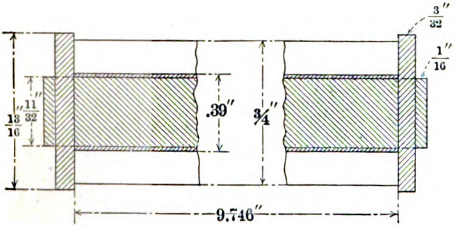

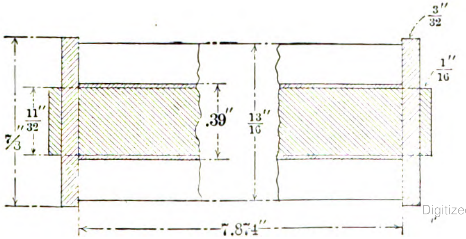

These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0527	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.608		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.235	.695
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.412

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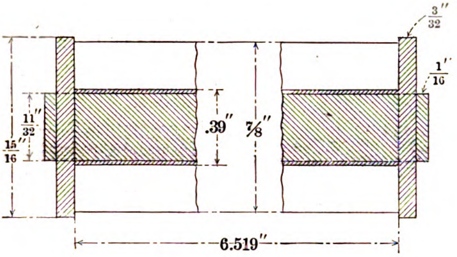

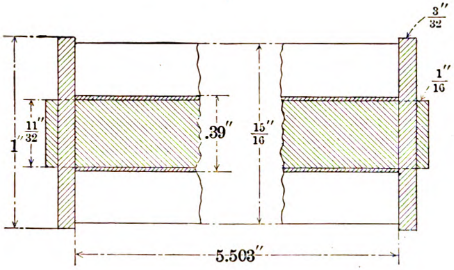

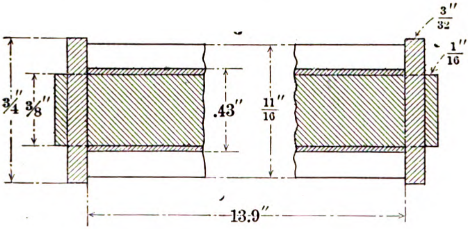

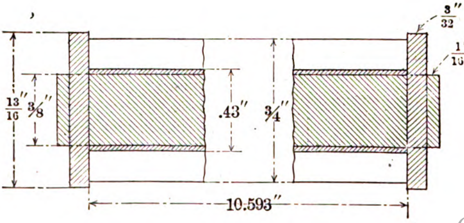

These bobbins, wound with ar wire indicated in first column, wi.. contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 75 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0527	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.608		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.235	.695
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
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36	1340.	.329	1930.	.409
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38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.412

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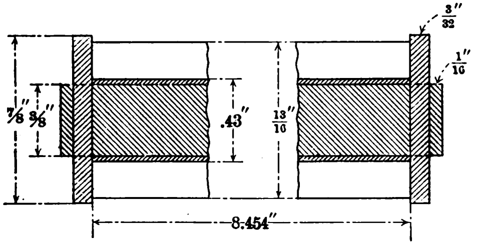

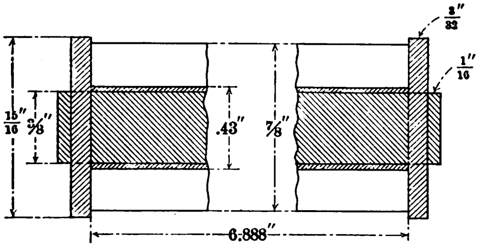

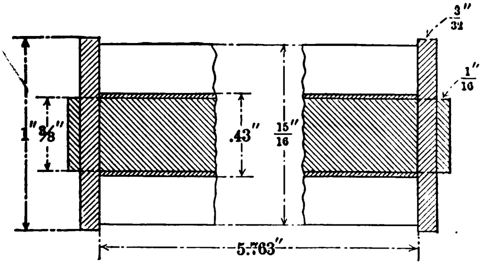

These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fabr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.03155	.7		
11	.03375	.689		
12	.0527	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.335	.695
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
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40	5360.	.252	12690.	.413

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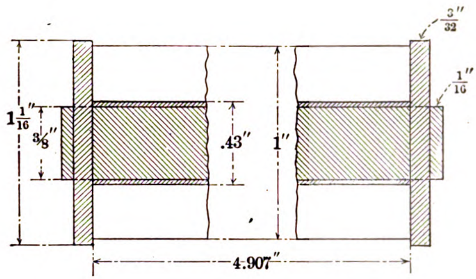

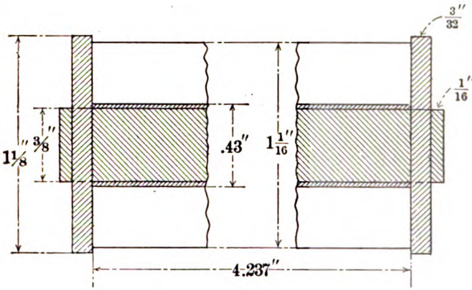

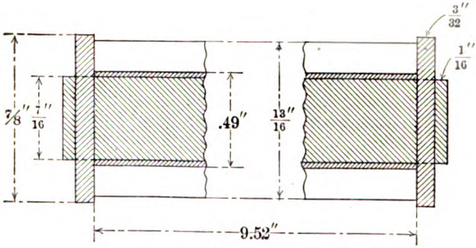

These bobbins, wound with any wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0527	.675		
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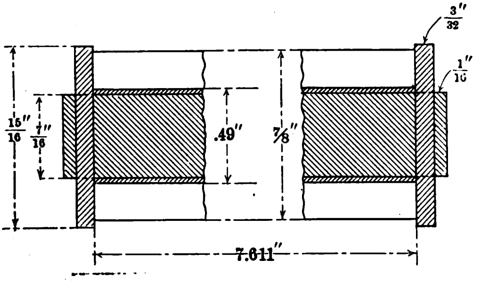

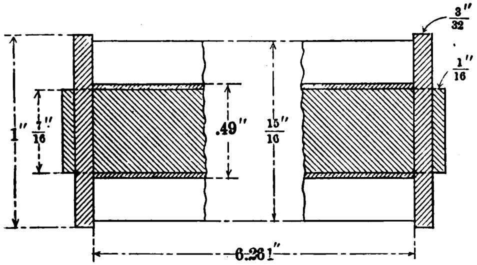

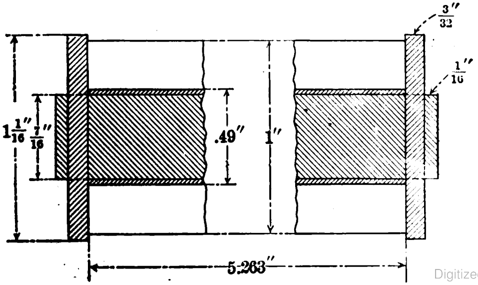

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The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
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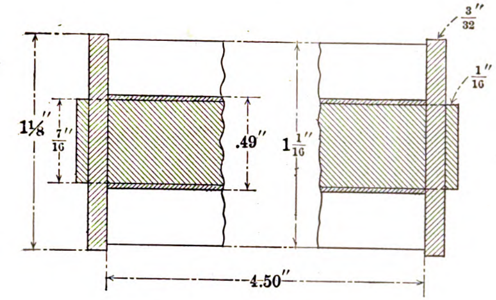

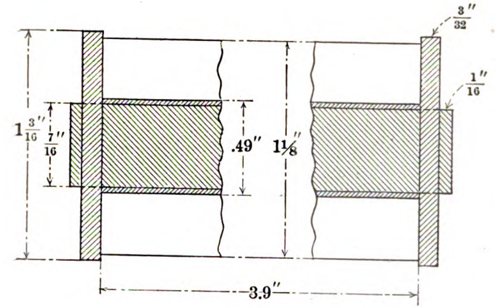

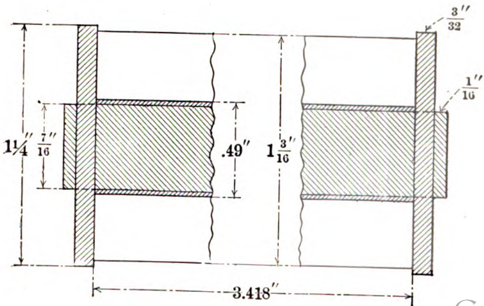

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SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
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40	**5360.**	**.252**	**12690.**	**.412**

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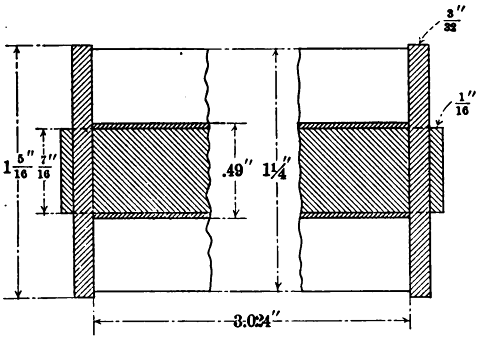

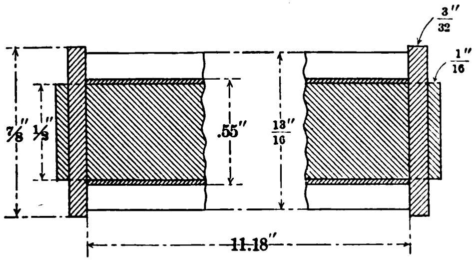

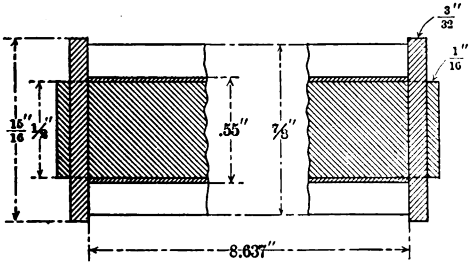

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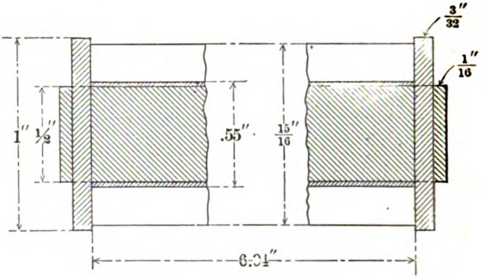

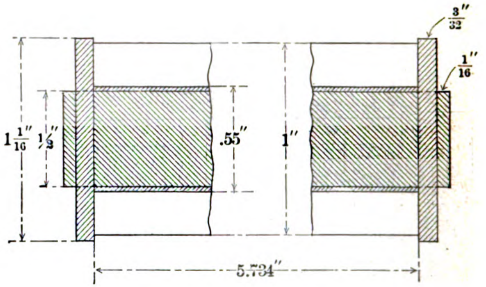

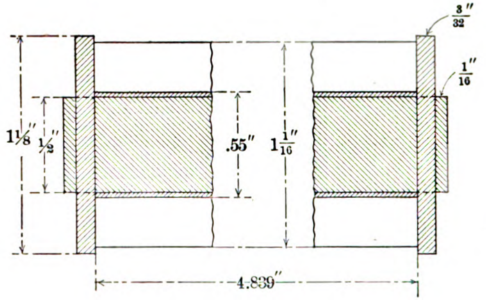

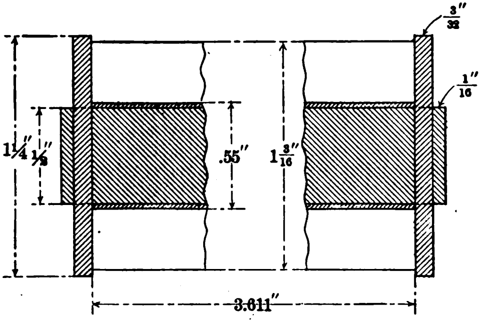

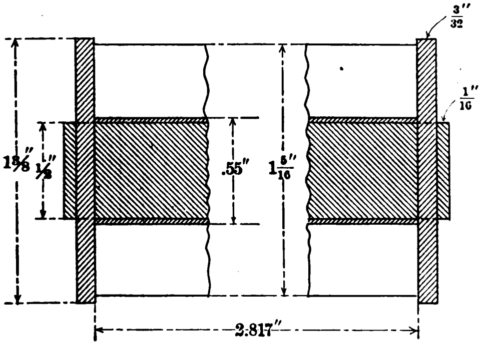

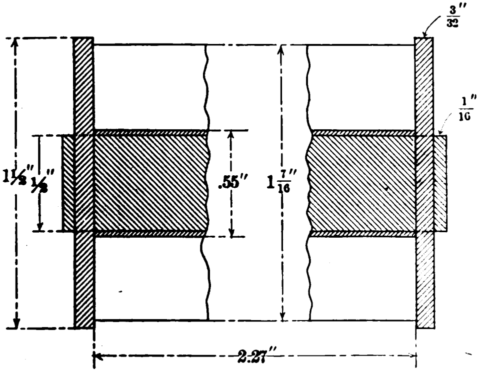

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SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
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23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.452
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.439
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.412

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LOGARITHMS OF NUMBEBS.

Natural Numbers.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

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LOGARITHMS OF NUMBERS.

Natural Numbers.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9965	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

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ANTILOGARITHMS.

Logarithms.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

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ANTILOGARITHMS.

Loga-rithms.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6633	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

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8ths.	16ths.	32ds.	64ths.	Decimal Equivalent
			1	.015625
		1		.03125
			3	.046875
	1			.0625
			5	.078125
		3		.09375
			7	.109375
1				.125
			9	.140625
		5		.15625
			11	.171875
	3			.1875
			13	.203125
		7		.21875
			15	.234375
				.25
			17	.265625
		9		.28125
			19	.296875
	5			.3125
			21	.328125
		11		.34375
			23	.359375
3				.375
			25	.390625
		13		.40625
			27	.421875
	7			.4375
			29	.453125
		15		.46875
			31	.484375
				.500000
			33	.515625
		17		.53125
			35	.546875
	9			.5625
			37	.578125
		19		.59375
			39	.609375
5				.625
			41	.640625
		21		.65625
			43	.671875
	11			.6875
			45	.703125
		23		.71875
			47	.734375
				.75
			49	.765625
		25		.78125
			51	.796875
	13			.8125
			53	.828125
		27		.84375
			55	.859375
7				.875
			57	.890625
		29		.90625
			59	.921875
	15			.9375
			61	.953125
		31		.96875
			63	.984375

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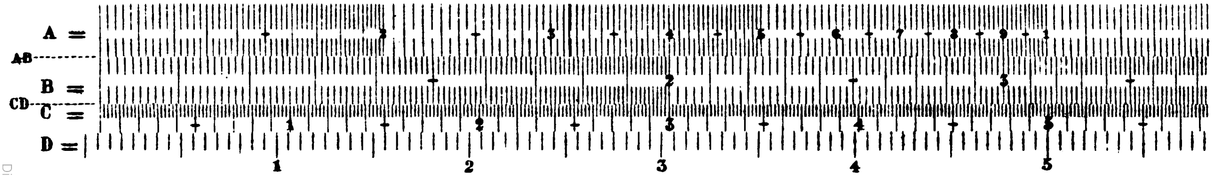
This logarithmic scale gives the squares, cubes, square roots, cube roots and the logarithms of all numbers from one to infinity. With the assistance of the logarithms any root or power of any number can immediately be found.

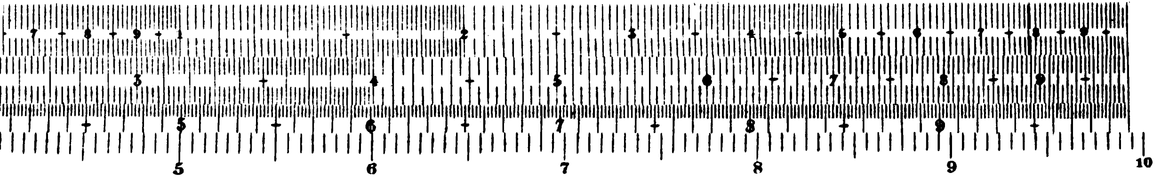
<—— LEFT HAND OF SCALE "A" READS FROM —×—

1	to	10
100	"	1000
10000	"	100000



—×— RIGHT HAND OF SCALE "A" READS FROM ——>

10	to	100
1000	"	10000
100000	"	1000000



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Referring to line A B all numbers above are the squares of the numbers immediately below.

All numbers below are the square roots of the numbers immediately above.

Referring to line C D, all numbers below, in scale C are mantissas of the logarithms of the numbers above, in scale B, i. e., the mantissa of the logarithm is shown immediately below the numbers of scale B; the characteristic being found in the regular way.

Scale D is simply the rule divided into sixteenths of an inch.

To get the square and square root of any number:

Select any number in scale B, call the number 4. This number 4 is immediately under 16 in scale A, and 4 is the square root of 16.

Find 25 in scale B, then 25 times 25 is 625, which value in left hand of scale A is immediately above the 25 of scale B. It also follows that 25 is the square root of 625. If 25 is the square root of 625, 2.5 is the square root also of 6.25 and 250 is the square root of 62500. But to get the square roots of .625, 62.5 and 6250, these values are found on the right hand of scale A, in scale B between 6 and 7, the answer being .79+, 7.9+ and 79+ respectively.

A little practice will enable the operator to locate the decimal point. It will be observed that scale A runs from left hand, commencing at 1, the middle of the scale being 10. The extreme right hand end of the scale being 100. The left hand of scale A therefore reads from 1 to 10 or 100 to 1000 or 10000 to 100000. The right hand of scale A reads from 10 to 100, from 1000 to 10000 and from 100000 to 1000000. This will explain the reason for finding the square root of 6.25, 625 and 62500 immediately under line AB, left hand of scale A, whereas the square root of .625, 62.5 and 6250 will be found under the line AB, right hand of scale A in scale B.

To find the cube root of any number:

Select the number from scale B. Take for instance number 27: first put down the characteristic of the logarithm, which is 1, the mantissa is immediately under 27 in scale C under the line CD. This mantissa is .431, therefore the logarithm of 27 is 1.431; dividing this value by 3 we get .477. Find value .477 in scale C located along the line CD; immediately above .477 we find 3 in scale B, which is the number required or the cube root of 27. We will next take the number 270; the characteristic will be 2. Get the mantissa the same as that of 27, viz., .431; hence the logarithm of 270 is 2.431, and dividing this logarithm by 3 we get the logarithm of the cube root of 270, or .81; then looking along the line CD in scale C find .81 and immediately above .81 is 6.45+ in scale B, which is the cube root of 270. The decimal point in the answer being fixed by the characteristic, hence the characteristic being zero the answer is 6 45 plus. To get the 4th, 5th, 6th and 7th root the logarithm is divided by 4, 5, 6 and 7 respectively.

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See also

C.R. Underhill "Elec. World" Dec. 21st 1907

" " " – Jan 1909

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